

Note that the times shown in the study plan overleaf do not include the time that you will need to answer questions on the DVD and the TMA, making use of the set book, watching the TV programme, attending sessions at your local or regional centre or reflecting on what you have learned and how you have learned it. Past students have also commented that *our* estimates of the times needed for the study of the DVD-multimedia activities are likely to be low.

## Study Guide for Block 8

*Discovering Science* is divided into two halves. In the first half of the course we have taken the world apart, starting with the Earth and the Universe, and moving down the scale of sizes. The second half of the course builds the world back up again, starting with atoms, and Block 8 marks the beginning of this process.

This block is divided into three parts. In the first part, Sections 2 to 5, the understanding of the structure of atoms that you developed in the first part of Block 7 is applied to classify and interpret the properties and structures of chemical compounds. This also helps to explain the distribution of the elements in the Periodic Table that you met in Block 6. In the second part, Sections 6 to 11, we concentrate on important features of chemical reactions: the energy changes associated with reactions; factors that determine the amount of product that is formed and how fast a reaction proceeds. Then in the last part of the block, Sections 12–17, we examine some of the ways that this chemistry is applied in the developed world. Our main topic is crude oil and petrochemicals, and this is used to introduce the chemistry of carbon compounds.

Most of the blocks up to now have been building on knowledge and skills acquired in earlier blocks. In Block 8 we start the process of drawing this knowledge together. Also, you will apply skills in new contexts, so you will see how they can be transferred from one area of study to another.

The study plan overleaf shows the components of Block 8. As in Block 6 the two DVD-video activities are used to demonstrate experiments. The first shows some of the contrasting properties of different substances that are introduced in the preceding section of the book. The second is used in rather a different way; it introduces features of reactions that you will meet in the subsequent sections. You may wish to view this DVD-video more than once.

The practical activity (7.1) should be carried out sometime during your study of Section 7, and there is an additional optional practical activity (15.3) associated with Section 15. The equipment and most of the chemicals required for these practical activities are likely to be available in the home, but you may need to buy a few chemicals at a pharmacy. Please make sure that you check what you need well ahead of time.

There are three main DVD packages relating to Block 8, and two of these are designed to be studied in more than one session. In Activity 8.1 you will need to use the S103 graph plotter; if you did not use this in Block 7, you should make time before Section 8 to work through the audio introduction on the Block 7 DVD. In addition, we introduce an application called WebLab, which will enable you to visualize the three-dimensional shapes of the molecules of many of the chemical compounds that you meet in Sections 12–16. Activity 12.2 introduces you to this package, and after studying this activity you can use WebLab when you wish to view compounds introduced in the text. As in previous blocks there are some questions on the DVD that allow you to assess your understanding of the block. The most appropriate times to do these would be after completing the three main parts of the block, that is, after Sections 5, 11 and 17.

Block 8 is assessed in TMA06. The cut-off date for this assignment is listed in the *Study Calendar*.








A three week period is allocated for studying Block 8, and the study plan overleaf gives estimates of the times required for each section.

Two TV programmes are particularly relevant to the material in Block 8: 'Liquid crystals' and 'Hidden visions'. The transmission times can be found in the *Study Calendar*.



# 8 Building with atoms

All study times are in hours

Week	Sections of Book 8	Total study time	DVD-multimedia, DVD-video and practical activities
1	1 Introduction		
	2 Electrons in atoms: a look forward and a look back	$\frac{1}{4}$	
	3 Electron configurations	$2\frac{1}{2}$	multimedia  3 4
	4 Chemical bonding: ionic compounds and molecular substances	$1\frac{1}{2}$	video  1 2
	5 Explaining chemistry through electron structure	$1\frac{3}{4}$	
	6 Chemical reactions and energy changes	$2\frac{1}{2}$	video  1 2
	7 Water	$2\frac{1}{2}$	 1 2
	8 Chemical equilibrium	$3\frac{1}{2}$	multimedia  1
2	9 Acids and bases: a quantitative view	$1\frac{1}{2}$	
	10 Rates of chemical reactions	1	
	11 Supplying nitrogen for crop production: a case study	$\frac{3}{4}$	
	12 The chemistry of carbon compounds: crude oil	3	multimedia  1
3	13 What else is oil used for?	1	
	14 Functional groups and their reactions	3	multimedia  1 2
	15 Polymers	$2\frac{1}{2}$	
	16 Pharmaceuticals	2	
	17 Epilogue	$\frac{3}{4}$	

'Liquid crystals' and 'Hidden visions' should be viewed at some time during or immediately after your study of Block 8.



## Study File for Block 8

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### Notes on activities

You should read through the notes for each activity before attempting it. After completing an activity you should study the relevant comments in the next section of the Study File. No estimate of time is given for activities that should take 10 minutes or less.

#### Activity 3.1 Working out the electron configurations of atoms 1–20

Table 3.1.1 shows the first 20 elements. We have already assigned electron configurations to six of these atoms. Work out the 14 missing electron configurations and complete the table. Figure 3.3 in the book contains some essential information for this activity.

**Table 3.1.1** The electron configurations of atoms of the first 20 elements.

Atom	Atomic number	Electron configuration
H	1	$1s^1$
He	2	$1s^2$
Li	3	$1s^2 2s^1$
Be	4	$1s^2 2s^2$
B	5	$1s^2 2s^2 2p^1$
C	6	$1s^2 2s^2 2p^2$
N	7	$1s^2 2s^2 2p^3$
O	8	$1s^2 2s^2 2p^4$
F	9	$1s^2 2s^2 2p^5$
Ne	10	$1s^2 2s^2 2p^6$
Na	11	$1s^2 2s^2 2p^6 3s^1$
Mg	12	$1s^2 2s^2 2p^6 3s^2$
Al	13	$1s^2 2s^2 2p^6 3s^2 3p^1$
Si	14	$1s^2 2s^2 2p^6 3s^2 3p^2$
P	15	$1s^2 2s^2 2p^6 3s^2 3p^3$
S	16	$1s^2 2s^2 2p^6 3s^2 3p^4$
Cl	17	$1s^2 2s^2 2p^6 3s^2 3p^5$
Ar	18	$1s^2 2s^2 2p^6 3s^2 3p^6$
K	19	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$
Ca	20	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$



### Activity 3.2 Working out electron configurations at high atomic number

For this activity, you need to apply the same techniques that you used in Activity 3.1, but at much higher atomic numbers. According to Figure 3.9, rubidium (Rb) is a Group I alkali metal and radium (Ra) is a Group II metal.

- (a) What are the outer electron configurations of the atoms of these two elements?
- (b) Now use Figures 3.6 and 3.7 to work out and write down the full electron configurations of the rubidium and radium atoms. Do these configurations agree with your answer to the first part of this question?



### Activity 3.3 Electron configurations and chemical periodicity

*(The estimated time for this activity is 40 minutes.)*

The CD-ROM activity 'Chemical periodicity and electron structure' will reinforce your understanding of the shells and sub-shells occupied by electrons in atoms, and the relationship between electron configurations and chemical periodicity. It covers the same ground as Sections 2 and 3 in a different way, and provides valuable self-assessment and revision questions.

*'Chemical periodicity and electron structure' is on the Block 8 CD-ROM. You should study it now.*



### Activity 4.1 Viewing the properties of ionic compounds and molecular substances

*(The estimated time for this activity is 30 minutes.)*

This video activity supports Section 4 by demonstrating differences in the properties of ionic compounds and molecular substances using iodine, sulfur, carbon disulfide and two alkali metal halides, sodium chloride and potassium iodide. The experiments include the following:

- 1 Contrasting the melting temperatures of carbon disulfide, iodine and sulfur with those of alkali metal halides.
- 2 Contrasting the solubilities of iodine, sulfur and sodium chloride in carbon disulfide — a solvent that resembles grease-removing liquids like petrol.
- 3 Contrasting the electrical conductivity of liquid sulfur with that of molten alkali metal halides.
- 4 Contrasting the solubilities of sodium chloride and sulfur in water.
- 5 An investigation of differences in the structures of solid iodine, solid sulfur and solid sodium chloride.

As you watch, use Table 4.1.1 to note your observations in the Comments column, and your conclusion as to whether the substance is ionic or molecular.

*The video 'Classifying chemical compounds' is on Videocassette 2 (64–107). You should view this video now.*

**Table 4.1.1** Properties of ionic compounds and molecular substances.

Property	Substance	Comments	Ionic or molecular
melting temperature	carbon disulfide		
	iodine		
	sulfur		
	alkali metal halide		
solubility in carbon disulfide	iodine		
	sulfur		
	sodium chloride		
electrical conductivity of melt	sulfur		
	alkali metal halide		
solubility in water	sodium chloride		
	sulfur		
structure of solid	iodine		
	sulfur		
	sodium chloride		

When you have finished watching the video and have completed Table 4.1.1, try summarizing the properties of ionic compounds and molecular substances by completing Table 4.1.2.

**Table 4.1.2** Summary of the properties of ionic compounds and molecular substances.

Property	Ionic compounds	Molecular substances
melting temperature		
electrical conductivity of melt		
solubility in water		
solubility in carbon disulfide		
structure of solid		



### Activity 6.1 The properties of chemical reactions

(The estimated time for this activity is 30 minutes.)

The video 'Features of reactions' demonstrates some of the important aspects of chemical reactions that you will meet in Sections 6–11. At various times you will be asked to make observations and record them in Tables 6.1.1–6.1.4.

The term 'concentration' is used in this video. This refers to the amount of substance dissolved in a given volume of solution; the concept will be fully discussed in Section 7.

The video 'Features of reactions' is on Videocassette 2 (108–211). You should view this video now.

**Table 6.1.1** The changes taking place in Reactions 1–3.

Reaction number	Observation
1	
2	
3	

**Table 6.1.2** Energy changes taking place in Reactions 4–6.

Reaction number	Energy changes observed
4	
5	
6	

**Table 6.1.3** Reaction 7: the colour changes that take place on heating and cooling. A pink solution indicates the presence of mainly reactant, a blue solution indicates the presence of mainly product, and a violet solution indicates a mixture of reactant and product.

Conditions	Colour at start	Chemicals present at start	Colour at end	Chemicals present at end
beaker of ice	violet	reactant and product		
beaker of hot water	violet	reactant and product		
<i>test-tubes are then swapped over</i>				
beaker of ice				
beaker of hot water				



**Table 6.1.4** The time taken for the colour change to occur.

Beaker	Concentration of reactants	Time/s
left-hand	highest	
2nd from the left	high	
centre	intermediate	
2nd from the right	low	
right-hand	lowest	

### **Activity 6.2 An alternative to petrol**

*(You should spend no more than 20 minutes on this activity.)*

This activity asks you summarize the information that has been presented so far about the use of ethanol as an alternative to petrol, to suggest other questions that need answering in order to compare these two fuels, and then to read an article to extract relevant information to help with this comparison.

(a) What information about the relative merits of ethanol and petrol as fuels has been given in the book?

(b) Make a list of questions that you think should be answered in order to compare ethanol and petrol as fuels for motor vehicles. You may find it useful to read again the discussion of the use of hydrogen as an alternative fuel, in the paragraph that preceded this activity in Section 6.3.1, since this may suggest some relevant issues to consider.

(c) Now read the article 'Energy and fuels', which was published in *New Scientist* in 1994 and is reprinted in Appendix 2. This article should answer some of the questions raised in part (b), though not necessarily all of them, and it may make you think of factors that you had not previously considered. After reading the article, make as complete a list as you can of the benefits and drawbacks of using ethanol instead of petrol as a motor fuel. Note we have given you a very specific goal to achieve by reading the article, and advice on how to achieve this is given in Box 6.2.1, *Reading articles*.

#### **Box 6.2.1 Reading articles**

The previous articles from newspapers and science magazines that we have asked you to read (in Block 3 Activity 7.1 (The Kobe earthquake) and Block 4 Activity 5.1 (Disposal of the Brent Spar oil platform)) were quite short. However, skills you developed in extracting information from those articles are equally useful when tackling longer articles. Remember that in the previous activities we recommended that you make sure that you know what information you are looking for before you start reading. Then you can skim-read the article to find relevant information (and ignore irrelevant parts), highlight the relevant information that you find, and also make some relevant notes. *SGSG* Chapter 2 contains much useful advice about reading and note taking, and you may wish to have another look at this chapter.

Articles reprinted from other sources differ from most of the S103 materials in that the authors would not have been writing specifically for S103 students; you should not therefore expect to understand every part of these articles. Also, when reading these articles, you usually need to extract specific information, and so it is not necessary to read all of the article in detail — this is particularly important when the article is quite long. With luck, the parts you don't understand will be in the sections that are not relevant, but this will not always be the case. Block 1 Box 6.3 suggests ways to cope with scientific text that you don't understand. You will be given further opportunities to practise reading articles which we don't expect you to understand fully as the course progresses.

We have been encouraging you to be critical of what you read. You were probably quite happy criticizing Edgar Wallace's chemistry in Block 6 Activity 6.5 (after all, that was *fiction*), and we hope that you are getting into the habit of looking critically at what you write. Don't forget that professional scientists and scientific journalists can sometimes be wrong, that some facts have more than one possible interpretation, and that theories change with time. Even if the science content of what you read is correct, it may be badly explained. So you should try to *read critically*, by asking yourself questions, such as:

- how does the content of the article relate to what I already know?
- has the author made assumptions that I know some facts or understand some principle which, in fact, I do not?
- has the author missed out important evidence supporting an idea being introduced?
- is the author wrong?



### Activity 7.1 Measuring the hydrogen ion concentration of household solutions

(The estimated time for this activity is 30 minutes.)

#### Equipment

##### KIT ITEMS

indicator papers (cut in half lengthways)

##### NON-KIT ITEMS

small containers to hold test solutions (clean yoghurt pots or plastic lids are ideal)

teaspoons

#### Chemicals

##### NON-KIT ITEMS

lemon juice (or other fruit juice)

vinegar

washing soda

baking powder

bicarbonate of soda

tap water

sparkling mineral water

ordinary household cleaning fluids (Flash liquid, ordinary household bleach, e.g. Domestos, etc.)

washing-up liquid or dishwasher powder

personal washing solutions (shampoo, soap, etc.)

#### Aims

In this activity you will apply your skill in designing experiments (developed in Block 2 Activity 2.1 and in Block 4 Activity 2.1) to a new situation. Your task is to measure the hydrogen ion concentrations of a variety of household solutions and thus to find out how these values relate to your intuitive ideas of which solutions are more acidic and which are less acidic.

#### Introduction

An acid yields hydrogen ions when it dissolves in water; this suggests that the more acidic a solution is the greater the concentration of hydrogen ions in it. In Block 6 you saw that litmus paper was red in acidic solutions and blue in alkaline solutions. To measure the hydrogen ion concentration in this activity you will use the indicator papers from your practical kit. These paper strips contain a mixture of dyes and they turn a range of different colours depending on the hydrogen ion concentration of the solution into which they are dipped. (You may have used papers of this type — which are sold in garden centres — to test the acidity or alkalinity of your garden soil.) If you look at the book of indicator papers you will see that the inside covers comprise a key that relates the colour of the paper to the 'pH'. Don't worry about the meaning of this term at the moment — it will be explained in Section 9. The relationship between pH and hydrogen ion concentration is given in Table 7.1.1. Note that the concentrations decrease from  $0.1 \text{ mol litre}^{-1}$  ( $1 \times 10^{-1} \text{ mol litre}^{-1}$ ) to  $1 \times 10^{-11} \text{ mol litre}^{-1}$ . You will get used to handling very small values like these in Section 9.

**Table 7.1.1** Obtaining the hydrogen ion concentration from the key on the indicator papers.

pH	Approximate concentration of hydrogen ions/mol litre <sup>-1</sup>
1	$1 \times 10^{-1}$
2	$1 \times 10^{-2}$
3	$1 \times 10^{-3}$
4	$1 \times 10^{-4}$
5	$1 \times 10^{-5}$
6	$1 \times 10^{-6}$
7	$1 \times 10^{-7}$
8	$1 \times 10^{-8}$
9	$1 \times 10^{-9}$
10	$1 \times 10^{-10}$
11	$1 \times 10^{-11}$



### Task 1 Thinking about design

Look back at the Block 2 and Block 4 practical work activities, and think about how you will tackle this activity, as defined in the aims. Note down things you will need to think about, your proposed method and how you will record your results.

Now look at the comments on this part of the activity before starting Task 2.

#### Practical procedure

##### **Safety precautions**

In addition to the precautions given in the *Practical work booklet*, care is needed when handling some of the chemicals. Always remember to read any instructions on the container before using the chemicals.

Washing soda and other household cleaning fluids may be harmful if swallowed and may irritate eyes on contact.

### Task 2 Obtaining and recording the results

- 1 Collect together all the liquids and solids to be tested — you should aim to test at least eight.
- 2 For solids, such as washing soda and bicarbonate of soda, you will first need to make a saturated solution — one that contains undissolved solid — with tap water. To do this put a teaspoonful of the solid in a small container and add several teaspoonfuls of tap water such that most, but not all, of the solid dissolves. Make sure you label these samples clearly and correctly so that they do not get mixed up.
- 3 Cut the indicator papers in half lengthways. *Don't use them all for this activity: keep one for use with Activity 15.3.*
- 4 In turn, test each liquid or solution as follows:
  - Pour a small amount of liquid into a small container; for many liquids the top of its container will be ideal.
  - *Using a new, clean indicator paper strip for each solution tested*, dip the paper into the solution so that between 1 and 2 cm has been immersed. Take the paper out of the solution and carefully shake off any drips.
  - Compare the colour of the indicator paper with the colour key in the indicator paper booklet and note down in Table 7.1.2 the pH value corresponding to the colour that matches best. You may find it difficult to decide between two colours, in which case you should write down a range. You should write a comment each time to say how sure you are of the value you've recorded.
  - Then use Table 7.1.1 to convert this pH value into a hydrogen ion concentration and write it down in Table 7.1.2.
  - For reference during the investigation, you may find it interesting to place the coloured indicator strips on a sheet of white paper with the name of the liquid tested alongside.
  - Pour the tested liquid down the sink and wash the container used thoroughly.

**Table 7.1.2** Results of measuring the hydrogen ion concentration of household solutions. You do not have to complete all rows in the table but try to test as many different substances as you can; some blank rows have been included for additional substances you might have available.

Solution	pH	Approximate concentration of hydrogen ions/mol litre <sup>-1</sup>	Comments
tap water			
freshly boiled tap water			
sparkling mineral water			
lemon juice			
vinegar			
bicarbonate of soda			
washing soda			
ordinary household bleach			
washing-up liquid			
dishwasher powder			
hair shampoo			

- 5 Now investigate the effect of diluting some of the solutions. Choose three solutions: one with a lowish hydrogen ion concentration, about  $1 \times 10^{-11}$  mol litre<sup>-1</sup>; one with a highish hydrogen ion concentration, about  $1 \times 10^{-3}$  mol litre<sup>-1</sup>; and one with an intermediate hydrogen ion concentration, about  $1 \times 10^{-7}$  mol litre<sup>-1</sup>. Dilute these solutions as follows, using a clean dry container for each diluted solution.
  - Put one teaspoonful of the substance (or saturated solution, taking care not to include any undissolved solid) in a container, and add 9 teaspoonfuls of tap water. The substance has thus been diluted to one-tenth of its original strength.
  - Put one teaspoonful of the solution you have just diluted by a factor of ten in another container, and add 9 teaspoonfuls of tap water. The substance has thus been diluted to one-hundredth of its original strength. (Alternatively, you can use larger volumes and do the dilutions in a measuring jug.)
  - Make sure you label the samples clearly and correctly so that they do not get mixed up.
  - Use the indicator paper strips as before to measure the hydrogen ion concentrations and record your results in Table 7.1.3.



[illegible]

## Analysis of results

From Task 2 what can you conclude about:

- ## Review

When you have completed the investigation, think back over it and note down what you did well, and where you could make some improvements.

## Part I

The first part of this CD-ROM activity introduces you to the idea of chemical equilibria in reactions between gases. There are three sections: introduction; effect of pressure; effect of temperature. At various points in the activity you are asked to note down your observations, and you should use the following tables for this.

## Introduction

Note down in Table 8.1.1 the number of red product 1 molecules you count each time you stop the reaction, both when you start with 'reactant' molecules and when you start with 'product' molecules.

Attempt	1	2	3	4	5	6	7	8	9	10	11
product 1 molecules counted — starting with 'reactants'	4	4	5	4	5	4	4	4	5	4	5
product 1 molecules counted — starting with 'products'	4	4	4	5	3	4	4	3	4	4	

### Effect of pressure

For each reaction you investigated, note down in Table 8.1.2 whether the proportion of product(s) decreased or increased or stayed the same as you increased the pressure.

**Table 8.1.2** Effect of increased pressure on proportion of product(s).

Reaction	Proportion of product(s) increased/decreased/stayed the same
<i>Set A</i>	
$\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \longrightarrow 2\text{NH}_3(\text{g})$	increased
$\text{CO}(\text{g}) + 2\text{H}_2(\text{g}) \longrightarrow \text{CH}_3\text{OH}(\text{g})^a$	increased
$2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \longrightarrow 2\text{SO}_3(\text{g})$	increased
<i>Set B</i>	
$2\text{NH}_3(\text{g}) \longrightarrow \text{N}_2(\text{g}) + 3\text{H}_2(\text{g})$	decreased
$2\text{NO}_2(\text{g}) \longrightarrow 2\text{NO}(\text{g}) + \text{O}_2(\text{g})$	decreased
$\text{PCl}_5(\text{g}) \longrightarrow \text{PCl}_3(\text{g}) + \text{Cl}_2(\text{g})$	decreased
<i>Set C</i>	
$\text{H}_2(\text{g}) + \text{I}_2(\text{g}) \longrightarrow 2\text{HI}(\text{g})$	stayed the same
$\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \longrightarrow 2\text{NO}(\text{g})$	stayed the same
$\text{CO}(\text{g}) + \text{H}_2\text{O}(\text{g}) \longrightarrow \text{CO}_2(\text{g}) + \text{H}_2(\text{g})$	stayed the same

<sup>a</sup>  $\text{CH}_3\text{OH}$  is called methanol

### Effect of temperature

For each reaction you investigated, note down in Table 8.1.3 whether the proportion of product(s) increased or decreased or stayed the same as you raised the temperature.

**Table 8.1.3** Effect of increased temperature on proportion of product(s)

Reaction	Enthalpy change	Proportion of product(s) increased/decreased/stayed the same
<i>Set A</i>		
$\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \longrightarrow 2\text{NH}_3(\text{g})$	$\Delta H = -92.2 \text{ kJ}$	decreased
$\text{H}_2(\text{g}) + \text{I}_2(\text{g}) \longrightarrow 2\text{HI}(\text{g})$	$\Delta H = -9.4 \text{ kJ}$	decreased
$2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \longrightarrow 2\text{SO}_3(\text{g})$	$\Delta H = -197.8 \text{ kJ}$	decreased
$\text{CO}(\text{g}) + \text{H}_2\text{O}(\text{g}) \longrightarrow \text{CO}_2(\text{g}) + \text{H}_2(\text{g})$	$\Delta H = -41.2 \text{ kJ}$	decreased
<i>Set B</i>		
$2\text{NH}_3(\text{g}) \longrightarrow \text{N}_2(\text{g}) + 3\text{H}_2(\text{g})$	$\Delta H = 92.2 \text{ kJ}$	increased
$\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \longrightarrow 2\text{NO}(\text{g})$	$\Delta H = 180.6 \text{ kJ}$	increased
$\text{CO}_2(\text{g}) + \text{H}_2(\text{g}) \longrightarrow \text{CO}(\text{g}) + \text{H}_2\text{O}(\text{g})$	$\Delta H = 41.2 \text{ kJ}$	increased
$\text{PCl}_5(\text{g}) \longrightarrow \text{PCl}_3(\text{g}) + \text{Cl}_2(\text{g})$	$\Delta H = 87.9 \text{ kJ}$	increased



## Part II: after Section 8.2

(The estimated time for this part of the activity is 30 minutes.)

Part of this activity involves plotting a graph using the S103 Graph Plotter. If you have not already done so, listen to the audio introduction to this program (on the Block 7 CD-ROM) before starting the activity.

In this part of the activity you will investigate the effects of changing the concentrations of reactants or products on chemical equilibrium. The reactions in the final section of 'Chemical equilibrium' involve ions in solution. You met chemical equations for compounds that form ions in solution in Block 6. The equations here are similar, except that we have left out ions that do not react. For example, if in a solution of sodium chloride, the chloride ions take part in a reaction but the sodium ions do not, then we can leave the sodium ions out of the equation. The sodium ions in such a case are called 'spectator' ions.

'Chemical equilibrium' is on the Block 8 CD-ROM. You should study the final section, 'Effect of concentration', now.

### Effect of concentration

Use the space below to make notes about the changes in the equilibrium concentrations of the other ions when you increase the concentration of either a product or reactant.

Record the gradient of the line you plot in Table 8.1.4.

**Table 8.1.4** The value of the gradient of a graph of product concentrations multiplied together against reactant concentrations multiplied together.

Reaction	Gradient
$\text{BrO}_3^-(\text{aq}) + \text{Cl}^-(\text{aq}) \longrightarrow \text{ClO}_3^-(\text{aq}) + \text{Br}^-(\text{aq})$	
$\text{HIO}_3(\text{aq}) \longrightarrow \text{H}^+(\text{aq}) + \text{IO}_3^-(\text{aq})$	
$\text{H}^+(\text{aq}) + \text{SO}_4^{2-}(\text{aq}) \longrightarrow \text{HSO}_4^-(\text{aq})$	1.2757 x 10
$\text{H}_3\text{PO}_4(\text{aq}) \longrightarrow \text{H}_2\text{PO}_4^-(\text{aq}) + \text{H}^+(\text{aq})$	
$\text{H}^+(\text{aq}) + \text{NO}_2^-(\text{aq}) \longrightarrow \text{HNO}_2(\text{aq})$	1.70
$\text{HAc}(\text{aq}) \longrightarrow \text{H}^+(\text{aq}) + \text{Ac}^-(\text{aq})$	

*Note:* by clicking on the buttons at the head of the columns of the tables in the notebook on the screen, you can obtain data for the effect of adding reactant 2, product 1 and product 2, as well as the initial data that show the effect of adding reactant 1.

## Activity 8.2 Solving problems in chemistry

(The estimated time for this activity is 15 minutes.)

In Block 5 there were several activities (3.3, 3.4 and 4.1) that asked you to think about the way in which you solve problems, and by the end of Activity 4.1 you had developed a strategy for doing this. You may or may not have been using your strategy in the time since you studied Block 5, but now we would like you to think again about the way in which you solve problems. First of all, have a go at the following problem, applying your problem-solving strategy from Block 5.

For the dissociation of iodic acid,  $\text{HIO}_3$ , in water:



the equilibrium constant is  $K = 0.17 \text{ mol litre}^{-1}$  at  $25^\circ\text{C}$ . If a solution is prepared in which the equilibrium concentration of  $\text{H}^+(\text{aq})$  is  $0.1 \text{ mol litre}^{-1}$  at  $25^\circ\text{C}$ , what will be the concentration of undissociated iodic acid in this solution?

After tackling the problem, think briefly about how you went about it, and then look at the comments on the activity, which include answers from two students.

## Activity 10.1 Maximizing the yield of a product: a compromise between rate and equilibrium

When you think about the optimum conditions under which to operate a reaction you need to consider both how the equilibrium yield is affected and how the rate of reaction is affected. Consider the following question and the way you would tackle it.

One step used in the manufacture of the plastic PVC is the production of 1,2-dichloroethane ( $\text{CH}_2\text{ClCH}_2\text{Cl}$ ) from ethene ( $\text{C}_2\text{H}_4$ ). (Do not worry about the names of the chemicals at this stage; chemicals like these will be introduced in Sections 12–17.) The equation for the reaction is



What would be the effects on this reaction of increasing the temperature, of increasing the pressure in the reaction vessel, and of using a catalyst?

(a) First write down the general strategy you use in tackling questions that involve changes in equilibrium yields and in reaction rates. You may find it helpful to look back at Questions 8.1, 8.2, 10.1 and 10.3–10.5 in order to say what your general strategy is.

(b) Now use your strategy to answer the question above.

## Activity 11.1 Constructing and understanding an argument

Most of the communication skills developed so far in the course relate to summarizing material in your own words and structuring a piece of writing in a logical order. The next stage is to start to put things together for a particular purpose, such as to argue the case for or against something. We use the word 'argument' in science differently from the meaning in everyday life. What we mean is that we follow a logical sequence of ideas until we can formulate a conclusion. As scientists, we often begin with experimental observations, and then try to formulate or make use of a theory that can explain them. However, sometimes we meet the arguments set out the other way round, when we begin with a concept and use it to explain some observation.

In this activity you will use knowledge gained in Sections 1–11 to consider a series of cases relating to some of the key features of constructing and understanding an argument — putting things in a logical order, considering hypotheses to explain evidence, and picking out flaws in arguments.

### Putting statements in a logical order

Each of Cases 1–4 consists of three statements, which should be arranged into a logical order with the addition of linking words, following the example given in each case.



### Case 1

Statement X *because* Statement Y *and* Statement Z.

- A In aqueous solution the ions are free to move around.
- B An aqueous solution of an ionic compound conducts electricity.
- C An ionic compound is made up of ions.

### Case 2

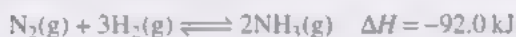
Statement X *because* Statement Y *and* Statement Z.

- A HCl is a strong acid.
- B When the concentration of hydrogen ions in a solution is  $1.0 \times 10^{-n}$  mol litre<sup>-1</sup> then the pH is *n*.
- C The pH of a  $1.0 \times 10^{-2}$  mol litre<sup>-1</sup> aqueous solution of HCl is 2.

### Case 3

Statement X *and* Statement Y *because* Statement Z.

This refers to the reaction:



- A Increasing the overall pressure leads to an increased equilibrium yield of ammonia.
- B Le Chatelier's principle states that when a constraint is applied to a system in equilibrium, the position of equilibrium will move in the direction that opposes the effect of the constraint.
- C Increasing the temperature leads to a reduction in the equilibrium yield of ammonia.

### Case 4

Statement X *and* Statement Y, *which explains why* Statement Z.

- A Rubidium reacts violently with water.
- B The electron configuration of rubidium is  $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 5s^1$ .
- C The outermost electron is easily removed.

### Identifying the best hypothesis to explain an observation

In each case you should choose one statement from A–C that best completes the sentence given.

### Case 5

The dissociation of bromine molecules Br<sub>2</sub> to bromine atoms is an endothermic process *because*

- A Bromine is a member of the group of compounds known as halogens.
- B Bromine has the electron configuration  $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^5$ .
- C Energy is required to break the Br–Br covalent bonds.

### Case 6

Many ionic compounds dissolve in water *because*

- A They are able to conduct electricity when dissolved.
- B Water molecules cluster around the ions, attracted by interactions of oppositely charged ions.
- C The electronegativities of the atoms from which the ions are formed are very different.

### Case 7

Ammonia is a gas at 25 °C *because*

- A Ammonia is formed in the Haber-Bosch process.
- B Ammonia dissolves in water to form an alkaline solution.
- C Nitrogen and hydrogen have similar electronegativities, and so the compound formed from them, ammonia, is a molecular substance.

### Identifying the flaws in an argument

In each case you should choose the item from A–C that best explains why the statement is wrong; in other words you are completing the sentence 'This statement is wrong because ...'. Also explain why the other two items are the wrong choices.

### Case 8

When 0.01 mol of magnesium chloride  $\text{MgCl}_2$  is dissolved in sufficient water to make 100  $\text{cm}^3$  of final solution, the concentration of magnesium chloride is 0.1  $\text{mol litre}^{-1}$  and the concentration of chloride ions is also 0.1  $\text{mol litre}^{-1}$ .

- A It is not possible to quote concentrations in  $\text{mol litre}^{-1}$  if only 100  $\text{cm}^3$  of solution are made
- B The formula unit of magnesium chloride shows the presence of one magnesium ion and two chloride ions.
- C Magnesium chloride is an ionic compound.

### Case 9

When sodium hydroxide dissolves in water, it dissociates completely to give  $\text{Na}^+(\text{aq})$  and  $\text{OH}^-(\text{aq})$  ions, and so the pH remains at 7.

- A The increase in the concentration of hydroxide ions is accompanied by a decrease in the concentration of hydrogen ions, so the pH will increase.
- B The pH reflects the concentration of positive ions and thus must change as the concentration of sodium ions increases.
- C Sodium hydroxide is a weak acid.

### Case 10

Hydrogen bonding is an intermolecular interaction, which occurs when a hydrogen atom is covalently bonded to an electronegative atom and is also close to a strongly electronegative atom in another molecule. It is the presence of hydrogen bonds between the hydrogens of one molecule and the carbons of another that explains why octane ( $\text{C}_8\text{H}_{18}$ ) is a liquid.

- A Carbon is not strongly electronegative, and the hydrogens attached to carbon do not have partial positive charges
- B Octane is useful as a fuel because it is a liquid.
- C The hydrogen bonds are easy to break and so octane releases a lot of energy when it burns.



### Activity 12.1 Identifying patterns in structural formulae

The activity will help you to make sense of tables such as Table 12.1.1.

- (a) Look at the first column of Table 12.1.1; what do all the names have in common?
- (b) As you progress from the top to the bottom of the second column, how does the molecular formula change? In particular, what is the difference between adjacent pairs? Repeat this analysis for the structural formulae and abbreviated structural formulae in the third and fourth columns.
- (c) What is the trend in the boiling temperature, and what is the explanation for this trend?
- (d) Predict the molecular formula, structural formula, abbreviated structural formula and boiling temperature of the next member after octane.

**Table 12.1.1** The names, formulae and boiling temperatures (b. t.) of the first eight linear-chain hydrocarbons.

Name	Molecular formula	Structural formula	Abbreviated structural formula	b. t./°C
methane	CH <sub>4</sub>	$\begin{array}{c} \text{H} \\   \\ \text{H}-\text{C}-\text{H} \\   \\ \text{H} \end{array}$	CH <sub>4</sub>	-164
ethane	C <sub>2</sub> H <sub>6</sub>	$\begin{array}{c} \text{H} \quad \text{H} \\   \quad   \\ \text{H}-\text{C}-\text{C}-\text{H} \\   \quad   \\ \text{H} \quad \text{H} \end{array}$	CH <sub>3</sub> -CH <sub>3</sub>	-89
propane	C <sub>3</sub> H <sub>8</sub>	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \\   \quad   \quad   \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{H} \\   \quad   \quad   \\ \text{H} \quad \text{H} \quad \text{H} \end{array}$	CH <sub>3</sub> -CH <sub>2</sub> -CH <sub>3</sub>	-42
butane	C <sub>4</sub> H <sub>10</sub>	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\   \quad   \quad   \quad   \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\   \quad   \quad   \quad   \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$	CH <sub>3</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>3</sub>	0
pentane	C <sub>5</sub> H <sub>12</sub>	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\   \quad   \quad   \quad   \quad   \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\   \quad   \quad   \quad   \quad   \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$	CH <sub>3</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>3</sub>	36
hexane	C <sub>6</sub> H <sub>14</sub>	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\   \quad   \quad   \quad   \quad   \quad   \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\   \quad   \quad   \quad   \quad   \quad   \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$	CH <sub>3</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>3</sub>	69
heptane	C <sub>7</sub> H <sub>16</sub>	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\   \quad   \quad   \quad   \quad   \quad   \quad   \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\   \quad   \quad   \quad   \quad   \quad   \quad   \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$	CH <sub>3</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>3</sub>	98
octane	C <sub>8</sub> H <sub>18</sub>	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\   \quad   \quad   \quad   \quad   \quad   \quad   \quad   \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\   \quad   \quad   \quad   \quad   \quad   \quad   \quad   \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$	CH <sub>3</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>2</sub> -CH <sub>3</sub>	126

### Activity 12.2 The shapes of molecules

(The estimated time for this activity is one hour.)

- (a) This part of the activity involves studying the first two sections of the 'Organic molecules' package, which are called 'Introduction to organic molecules' and 'Shapes of organic molecules'.

*'Organic molecules' is on the Block 8 CD-ROM. After studying the section 'Shapes of organic molecules' you should read the summary of the section in the comments on this part of the activity before tackling part (b).*

(b) One of the skills that anyone beginning to study chemistry needs to develop is the ability to interpret a two-dimensional representation as a three-dimensional model. This is easier for some people than for others, but it is a skill that you can improve with practice. The molecular viewer software, WebLab, which we have provided on the Block 8 CD-ROM, will help with this. The section 'Visualising organic molecules' of the 'Organic molecules' package includes an interactive tutorial that introduces you to the use of the WebLab viewer, and you should study this now. Box 12.2.1 *Using WebLab to view structures in the text*, gives you some guidance.

*After studying the section 'Visualising organic molecules' you should attempt the following tasks, which test your understanding of the three-dimensional shapes of molecules*

#### **Box 12.2.1 Using WebLab to view structures in the text**

The three-dimensional structures of many of the compounds in the block are stored on the Block 8 CD-ROM. These compounds are identified in the book and the Study File by a superscript W. You can access these structures in two ways.

1▷ The first method does not require you to be using the 'Organic molecules' package – you open the WebLab viewer directly as you would any other application. To do this from Windows 95, click on Start, then Programs, then S103 Discovering Science, then WebLab Viewer. Alternatively, from Windows 3.1, click on Program Manager, then the S103 Discovering Science Program Group, then on WebLab Viewer.

The Viewer will open with a blank screen. To select the file for a particular molecule, click on File, and then on Open. You can then click on the number or name of the molecule that you wish to view. If you wish, you can open files for a number of different molecules, and you can compare their structures by displaying them side by side using the Tile option from the Window menu.

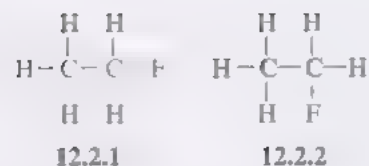
The drawback of this method is that the file names that are displayed in the Open dialogue box are abbreviated to eight characters. This is not a problem for the structures that are identified by numbers, nor for molecules with short names, but it is a problem for something like 2-methylpentane, which is abbreviated to 2methpan. For such molecules, a second method is preferable.

2▷ This method of using the Viewer requires you first to run the 'Organic molecules' package, and to start the 'Visualising organic molecules' section. Clicking on the WebLab button in the bottom half of the first screen of this section has the same effect as method 1 above. Alternatively, you can select a number or name from the list of available structures by clicking on the down arrow on the right of the text entry box. The list that is displayed is scrollable; when you have selected the molecule that you want to view, click on the WebLab button in the bottom half of the screen to run the Viewer with this molecule displayed. Once you have the Viewer open, you can select the files for additional molecules in the same way as in method 1, and you only need to return to the 'Visualising organic molecules' section for the long-named molecules that you can't identify from the abbreviated file names in the Open dialogue box. Note that each time you select a molecule from the list in this way you will open a new version of the Viewer, and this not only uses extra memory but it is also more difficult to compare molecules that are displayed in different versions of the Viewer. So wherever possible we recommend that you open files from within the Viewer.

Note that the molecule trypsin (discussed in Section 16), and the structures that you will meet if you decide to study Block 9, are not included in the list displayed in 'Visualising organic molecules', but they can be located and opened using the Open dialogue box within the WebLab Viewer (provided that the appropriate CD-ROM is inserted).

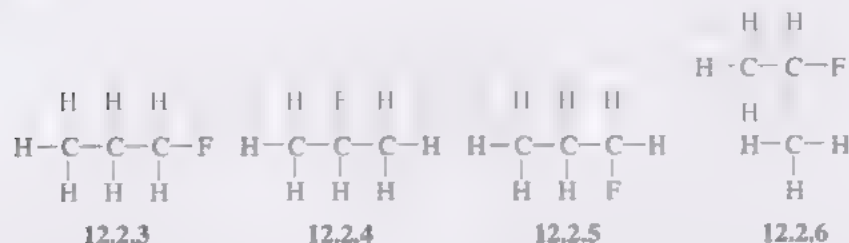
### Task 1

Structures 12.2.1<sup>W</sup> and 12.2.2 have the same molecular formula C<sub>2</sub>H<sub>5</sub>F. Are they representations of the same molecule, or are they isomers? You may wish to look at the appropriate file in WebLab to help you answer this question.



### Task 2

There are two isomers with the molecular formula C<sub>3</sub>H<sub>7</sub>F, and structures 12.2.3<sup>W</sup>, 12.2.4<sup>W</sup>, 12.2.5 and 12.2.6 show two representations of each of these isomers. Identify which pairs of structures represent the same isomer. Again use WebLab to help you do this.



### Task 3

How many different ways can you order:

- (a) two carbon atoms, five hydrogen atoms and one fluorine atom;
- (b) two carbon atoms, four hydrogen atoms and two fluorine atoms?

Draw the structural formula for each possibility.

### Task 4

Given three carbon atoms, seven hydrogen atoms and one fluorine atom, how many different isomers can you make?

## Activity 13.1 Summarizing chemical processes

So far in Sections 12 and 13 you have met four types of industrial reaction:

(i) hydrocracking, (ii) catalytic cracking, (iii) catalytic reforming, and (iv) isomerization (introduced in Question 12.8). Summarize the key points of each of the four processes and identify similarities and differences between them. Use equations where possible.

## Activity 14.1 An introduction to functional groups

(The estimated time for this activity is 30 minutes.)

In this activity you will study the final section of the 'Organic molecules' CD-ROM, which is called 'Functional groups of organic molecules'. This will introduce you to a number of different functional groups, and give you practice in identifying them and the reactions that they undergo.

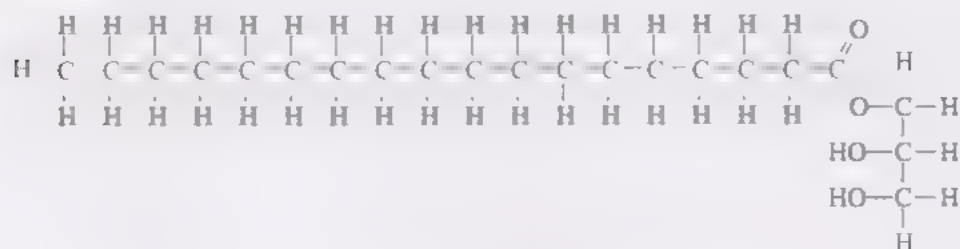
'Organic molecules' is on the Block 8 CD-ROM. You should study the final section now.



### Activity 14.2 Analysing the structure of organic compounds

(The estimated time for this activity is 15 minutes.)

Glyceryl monostearate, **14.2.1**, is a food additive sometimes referred to as E471. In this activity you will work out a strategy for analysing the structure of organic molecules like this.

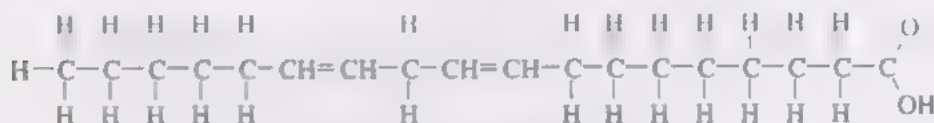


(a) Look at structure **14.2.1**, and try to identify any functional groups, carbon chains or carbon rings that are present. Make a note of the features that you have identified, perhaps by labelling the structure in pencil.

(b) Now think about how you tackled the identification of these parts of the molecule. Note down a list of steps that you took. These steps will comprise the basis of a strategy for analysing organic structures. Then compare your strategy with a strategy devised by a tutor in the comments section.

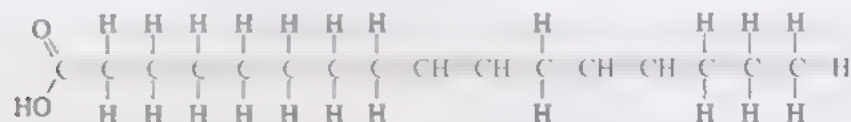
*Look at the comments on parts (a) and (b) of the activity before moving on to part (c).*

(c) In (b) you developed a strategy for analysing organic structures. Try out this strategy, or the tutor's strategy in the comments section, with linoleic acid, **14.2.2**, a polyunsaturated fatty acid that is essential for your health.



*Look at the comments on part (c) of the activity before moving on to part (d).*

(d) Now use your strategy to decide whether structure **14.2.3** is also linoleic acid.



### Activity 14.3 Drawing structural formulae

In Activity 14.2 you developed a strategy for analysing the structural formula of an organic molecule. Now you will reverse the process, and will draw structures based on a description in words.

Draw structural formulae of the three molecules described below. You should assume that all of the carbons are attached to each other by single bonds, unless specified, and that there are sufficient hydrogens to satisfy the valency of the carbons.

(a) A linear chain of eight carbon atoms. Attached to one end of this chain is a carboxylic acid group

(b) An ester in which the carbon of the ester group is attached to a linear chain of five carbons and the oxygen of the ester is attached to a chain of three carbon atoms.

(c) A chain of seven carbon atoms with an alcohol group attached to the third carbon from one end and a methyl group attached to the third carbon from the other end.

## Activity 14.4 Naming of organic compounds

*This is an optional activity that introduces the systematic method of naming organic compounds. In Section 12.2.4 we explained that we would use the systematic name for a compound unless the common name is in widespread use. We do not expect you to remember the names of organic compounds, nor to understand the conventions used for these names. However, if you are curious to find out the rationale behind some of the names that have been quoted, and if you have time to spare, then you may wish to read the following few paragraphs*

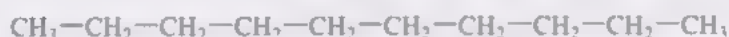
The systematic naming of organic compounds reflects the functional group approach. Attention is first focused on the carbon framework, and *then* on the functional group(s). The stem of the name is derived from the name of the corresponding linear-chain alkane given in Table 14.1.1.

**Table 14.1.1** The names of the first eight linear-chain alkanes.

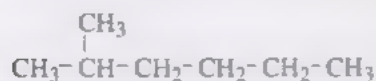
Name	Structural formula	Pronunciation
methane	$\text{CH}_4$	mee-thane
ethane	$\text{CH}_3\text{—CH}_3$	ee-thane
propane	$\text{CH}_3\text{—CH}_2\text{—CH}_3$	pro-pane
butane	$\text{CH}_3\text{—CH}_2\text{—CH}_2\text{—CH}_3$	bew-tane
pentane	$\text{CH}_3\text{—CH}_2\text{—CH}_2\text{—CH}_2\text{—CH}_3$	pen-tane
hexane	$\text{CH}_3\text{—CH}_2\text{—CH}_2\text{—CH}_2\text{—CH}_2\text{—CH}_3$	hex-ane
heptane	$\text{CH}_3\text{—CH}_2\text{—CH}_2\text{—CH}_2\text{—CH}_2\text{—CH}_2\text{—CH}_3$	hep-tane
octane	$\text{CH}_3\text{—CH}_2\text{—CH}_2\text{—CH}_2\text{—CH}_2\text{—CH}_2\text{—CH}_2\text{—CH}_3$	ock-tane

All of these compounds are called something-ane. It is the prefix, e.g. prop- or hept-, that tells you the number of carbons in the chain — three and seven, respectively. The suffix -ane identifies the compounds as alkanes. Notice that after the first few members of the family, the prefix follows the Greek method of counting.

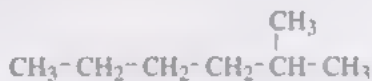
- The prefix dec- in decane comes from the Greek word for ten. What do you think the structure of decane looks like?
- Decane is a linear-chain alkane containing ten carbon atoms.



Let's now consider branched-chain alkanes such as 14.4.1<sup>W</sup>, which is called 2-methylhexane. It is a hexane because it is an alkane and the longest carbon chain is six carbons. The methyl prefix refers to the one-carbon branch, which comes off the second carbon from the left, hence the 2- in the name. 14.4.2<sup>W</sup> is also 2-methylhexane; it is the same molecule whether the methyl branch is attached to the second carbon from the left or the second from the right — the smallest number is always chosen, which is why it is not called 5-methylhexane. The name of the branch derives from the prefixes discussed earlier, followed by -yl; thus a three-carbon branch is propyl, and a six-carbon branch is hexyl.

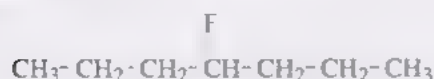


14.4.1



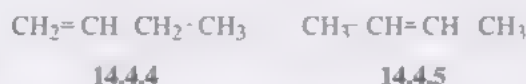
14.4.2

Halocarbons, such as 14.4.3<sup>W</sup>, are named in a similar way — this compound is called 4-fluoroheptane. The prefixes fluoro-, chloro-, bromo- and iodo- indicate which halogen is present, and the number tells us which of the carbons in the chain has the halogen attached to it.



14.4.3

**14.4.4<sup>w</sup>** is an alkene, because it contains a carbon–carbon double bond, its name is but-1-ene. The but- part indicates that the molecule contains four carbons in a row, the -ene part indicates that it contains a carbon–carbon double bond, and the 1 tells us that the double bond is between the first and second carbons from one end. It is important to put the number in because but-2-ene, **14.4.5<sup>w</sup>**, is a different compound.



What is the structure of pent-2-ene?



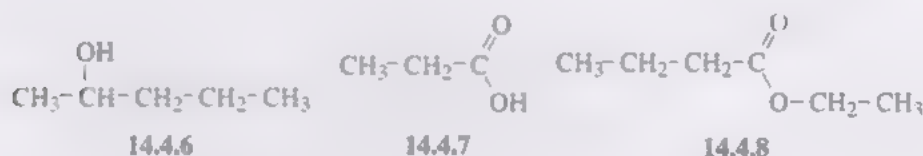
Pent- indicates a chain of five carbons, -ene suggests the molecule has a carbon–carbon double bond and the 2 tells us it is between the second and third carbons from one end — in this case it does not matter whether you choose the left or the right end



Alcohols are named using a similar strategy to alkenes. The prefix, e.g. pent- or oct-, indicates the number of carbons in the chain. This is followed by -anol to let us know it is an alcohol. A number inserted in the -anol tells us which of the carbons has the alcohol group attached to it; thus pentan-2-ol, **14.4.6<sup>w</sup>**, has the alcohol group attached to the second carbon in the chain

Carboxylic acids are relatively easy to name. **14.4.7<sup>w</sup>** is called propanoic acid. The prefix prop- is used because, including the carbon of the carboxylic acid functional group, there are three carbons in the chain. The carbon of the functional group is always the first carbon in the chain of carbons that gives rise to the basic name, so we do not need a number to identify the location of the group. The suffix -anoic acid tells us the compound is a carboxylic acid.

Esters have one functional group but two carbon chains. The name of an ester reflects the fact that they are made from a carboxylic acid and an alcohol. **14.4.8<sup>w</sup>** is called ethyl butanoate. It is called a butanoate because it was made from butanoic acid. The ethyl comes from the alcohol, ethanol, that was also involved. Thus the prefix to -anoate in the name of the ester refers to the number of carbons in the carboxylic acid used to make the ester, and the prefix to -yl refers to the number of carbons in the alcohol used to make it.

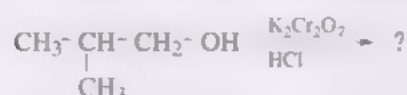


### Activity 14.5 Predicting the products of an organic reaction

(The estimated time for this activity is 15 minutes.)

In this activity you will develop a strategy for predicting the products of reactions of organic molecules that contain various functional groups.

(a) Predict the products of the following reaction:

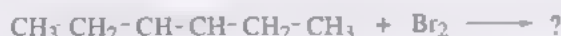


(b) Now think about how you arrived at your prediction. Make a note of the steps that you took, and then compare them with the method used by a member of the course team.

Look at the comments on this part of the activity before doing part (c).



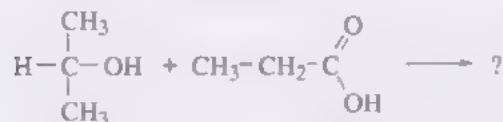
(c) Now use your strategy to predict the products of the following reaction:



Did your strategy work? If you had to revise your strategy, note any changes you made and why you made them.

Look at the comments on this part of the activity before doing part (d).

(d) Use your strategy to predict the products of the following reaction:



### Activity 15.1 Plastics in the home

Look around you and make a list of all the materials that you would call plastics or synthetic materials. Note down the appearance and properties of the different materials; for example, are they rigid, flexible, transparent, etc.? How do these properties match the function of the object?

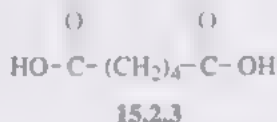
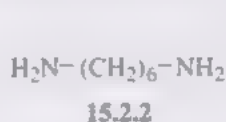
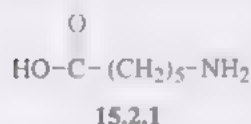
### Activity 15.2 The formation of nylon

(a) Question 15.1a demonstrated that a compound with one amine functional group reacts with a compound with one carboxylic acid functional group to give an amide. What kind of monomer would be required to form a polymer using this reaction?

(b) Based on the general reaction shown in Equation 15.2, predict the structure of the polymer formed using:

(i) the monomer 15.2.1;

(ii) the monomer 15.2.2 with the monomer 15.2.3.





### Activity 15.3 Demonstrating the relationship between the structure of poly(vinyl alcohol) and its physical properties

(This practical activity is optional but is great fun, especially if you want to amuse children of any age. It is likely to take you about one hour.)

#### Equipment

##### KIT ITEM

one strip of indicator paper cut in half lengthways

##### NON KIT ITEMS

2 screw-top glass jam jars

12 disposable plastic cups (yoghurt pots could be used for the experiments that do *not* require boiling water)

teaspoon

measuring jug

kettle

spatula

#### Chemicals

##### NON KIT ITEMS

borax

poly(vinyl alcohol) glue (Bostik Paper Glue or Glor Original Gum (other PVA adhesives will not work so well))

washing soda crystals

clear white vinegar or lemon juice

baking powder or sodium bicarbonate

#### Aim

To make cross linked polymers that behave like 'silly putty' and 'slime', and to think about how the differences in structure give rise to different properties.

#### Introduction

Poly(vinyl alcohol) is an addition polymer made from monomer units that contain an alcohol — OH — group; the monomer is a substituted alkene. The polymer is soluble in water, and the glue sold as Bostik Paper Glue or Glor Original Gum is a solution in water of poly(vinyl alcohol). It would normally be spread onto paper where it is absorbed and, over time, loses its solvent water and then glues the paper together.

When borax solution is added to the glue it forms cross-links between the polymer chains so that they cannot slide over each other so easily. Thus the glue solidifies as you add borax. In this activity you will investigate how the nature of the cross links is affected by the concentration of the borax solution and the presence of acid — vinegar (acetic acid) or lemon juice (citric acid) — or base (washing soda,  $\text{Na}_2\text{CO}_3$ ). You will also make a foamed polymer.

As you work through the practical procedure think about what your observations might mean in terms of the properties and reactions of polymers that you met in Section 15.

#### Practical procedure

##### Safety precautions

In addition to the precautions given in the *Practical work booklet*, care is needed when handling some of the chemicals. Always remember to read any instructions on the container before using the chemicals.

Washing soda may be harmful if swallowed and may irritate eyes on contact.

#### Making your stock solutions of borax and washing soda

It is best to make and keep your stock solutions in clean tightly-lidded screw-top, glass jam jars.

- 1 Using a measuring jug, put about 150 ml of water into a clean jam jar and stir in one teaspoonful of borax crystals. Stir well to dissolve as many crystals as possible. This is your stock borax solution.
- 2 Using a measuring jug, put about 200 ml of water into a clean jam jar and add half a teaspoonful of washing soda crystals. Close up the washing soda crystal packet and put it away somewhere safe. You will not need it again for this experiment. Test the solution with indicator paper; it should have a pH of 11.

#### Task 1 Making polymers with poly(vinyl alcohol) glue and borax

You can make up the three samples in cheap disposable plastic cups or yoghurt pots. All the reactants and products will wash out of the cups and can be disposed of down the kitchen sink.

##### Polymer A

- 1 Put two teaspoonfuls of poly(vinyl alcohol) glue in a disposable cup and add a teaspoonful of your stock borax solution. Stir well.
- 2 Take the polymer formed, Polymer A, out of the cup and put it on a flat plate, lid or tray. Observe if it 'flows' or not.
- 3 Leave it a few minutes and look again. Note down your observations.

### Polymer B

- 1 Put one teaspoonful of your stock borax solution in a disposable cup and add one teaspoonful of water and stir.
- 2 Put two teaspoonfuls of poly(vinyl alcohol) glue into a separate disposable cup and add one teaspoonful of the diluted borax solution you have just made. Stir well.
- 3 Put the polymer formed, Polymer B, next to Polymer A and compare them. Note down your observations.

### Polymer C

- 1 Put one teaspoonful of your stock borax solution into a disposable cup, add two teaspoonfuls of water and stir.
- 2 Put two teaspoonfuls of poly(vinyl alcohol) glue into a separate disposable cup and add one teaspoonful of the doubly-diluted borax solution you have just made. Stir well.
- 3 Put the polymer formed, Polymer C, next to Polymers A and B and compare them. Note down your observations.

(Note: If you want to keep these samples of polymers you will have to put them in a small plastic bag and exclude the air or they will dry out. If you want to make coloured polymer samples you can just add a few drops of food colouring to the teaspoonful of borax solution that you use to make the polymer.)

### Task 2 Solubility in water

For this task you can either use the three samples that you made in Task 1, or you can make new samples of each of Polymers A, B and C (as above). Divide each sample into four parts. Save one part for Task 3 and treat the other three parts as follows:

- 1 Put one part in one-third of a cup of cold water. Break it up with a spoon and stir to see if it dissolves. If it is still visible as a separate phase it has not dissolved.
- 2 Repeat 1 using hand-hot water.
- 3 Repeat 1 using water from a kettle that has just boiled.

Note down your observations for each polymer in Table 15.1.1.

**Table 15.1.1** The effect of adding water to Polymers A, B and C.

	Cold water	Hand-hot water	Boiling water
Polymer A			
Polymer B			
Polymer C			

### Task 3 The action of heat on the polymers

Put samples of Polymers A, B and C in separate cups and put the cups into a saucepan with 4cm of water that has just boiled. Do not let the cups fall over. Observe what happens to the polymers and note down your observations.

### Task 4 The action of acid and base on Polymer A

- 1 Make another sample of Polymer A.
- 2 Add one teaspoonful of vinegar or lemon juice. Stir well, breaking up the polymer until it has all dissolved in the acid.
- 3 Test the pH with indicator paper; it should be between 3 and 4.
- 4 Add one teaspoonful of the stock washing soda solution. A polymer, D, should form instantly. Compare Polymer D with a sample of Polymer A and note down your observations.



### Task 5 Making a foamed polymer

- 1 Make a sample of Polymer A and dissolve it completely in one teaspoonful of vinegar or lemon juice, as in Task 4.
- 2 Add a quarter teaspoonful of baking powder or sodium bicarbonate and quickly stir for a very short time. Then leave the mixture to stand and note down your observations.

Now turn to the comments on this activity for explanations of the observations you have made.

### Activity 17.1 The case for using alternative fuels

(The estimated time for this activity is 30 minutes.)

This activity builds on Activity 6.2, and has three parts to it. First you will read again the article 'Energy and fuels', and make a note of points that you now understand as a result of your study of Sections 12–17. Secondly you are asked to read and criticize a letter that supports one side of a debate about changing to renewable fuels. Then you will make a list of points that you might include in a reply to this letter.

(a) Look again at the article 'Energy and fuels' in Appendix 2, and identify the terms or concepts that you didn't understand when you first read the article but which you understand now that you have studied some organic chemistry in Sections 12–17. Do you still have some outstanding queries to which you would like an answer, and if so, how can you find the answers?

(b) The letter below appeared in response to the 'Energy and fuels' article.

Dear Editor

I disagree strongly with the suggestion in the article 'Energy and fuels' that more research and development money should be poured into developing renewable fuels. Our known reserves of oil will last us for several hundred years, and new oilfields are being discovered all the time, so it seems likely that there will be more than enough for the foreseeable future, to satisfy the needs of both chemists and motorists.

You say you are worried that the pollution caused by burning fossil fuels results in increased ill-health for city dwellers, particularly for those with bronchial problems, and you go on to suggest that we should use RME as fuel and devote an area of Britain as large as Wales to growing rapeseed oil. Many people are severely allergic to rapeseed pollen. I do not think the lives of those who live in the country should suffer to improve the lives of city dwellers. A better solution would be to impose an extra tax on all who take their cars within city limits, and so reduce the number of cars venturing into city centres.

It would be far better to turn our attention to producing electric cars. France produces a large proportion of its electricity from nuclear power, and here in Britain, AGR stations produce  $54.1 \text{ TWh y}^{-1}$  of electricity. There is no need to pour money into renewable energy sources such as noisy wind farms.

You cite Brazil as an example of a forward-looking country which makes use of alcohol from sugar cane as a fuel. In fact, the percentage of alcohol used there is falling, because it is so much more economical to use petrol. Also, RME, imported from Italy to this country, costs 24 p per litre, while petrol costs only 10 p. With these proven examples in front of us, it is folly to propose we do what Brazil has shown does not work.

Yours sincerely

Oz Titch

Note down any criticisms you have of this letter. You should draw on your knowledge of the chemical industry (Block 8 Sections 12–17) and of factors affecting climate change (Block 2), as well as on the article 'Energy and fuels'.

When criticizing someone's writing, you may find it useful to look out for where the author:

- omits important points;
- overstates the case, and draws conclusions that are not supported by facts;
- has facts wrong;
- has the facts correct, but draws wrong conclusions from them;
- makes unwarranted assumptions;
- omits supporting evidence;
- includes irrelevant information, or deviates from the point;
- draws conclusions based on one side of an argument;
- writes in a style inappropriate for the audience.

Of course, you should also recognize the places where the author has correct facts, supported by evidence, and draws the appropriate conclusions!

(c) If you were to write a letter in reply, what points would you make? We suggest that you make a note of these points in the form you find most convenient, for example, as a bullet-point list or as a spray diagram. You may also like to think about the order in which you would present the points.

### **Activity 17.2 Reviewing your study of Block 8: transferability of skills**

*(You should spend no more than 15 minutes on this activity.)*

As you have progressed through *Discovering Science*, you should have found that skills that you developed in a particular context can be used, perhaps with some modifications, in a variety of different contexts. This is true of learning skills, maths skills, communications skills, and also of the science skills that you have developed. You will also have discovered that the various areas of science that you have met are connected and interlinked in many different ways. For example, ideas about chemistry in this block are linked to the chemistry in Block 6, not surprisingly, but they are also linked to ideas about energy in Block 5, the structure of atoms in Block 7, water in Block 1, the carbon cycle in Block 2, etc. In this activity you will reflect on how well you have been able to transfer skills developed in other blocks to the context of Block 8, and how you can facilitate the transfer of both skills and knowledge from one context to another.

#### *Transferability of skills*

**Problem solving** We introduced a fairly formal procedure for solving problems in Block 5, where we were mainly concerned with various energy calculations. In Activity 8.2 of Block 8 we suggested that you use this approach to tackle a problem related to chemical equilibrium, and you may have used it, possibly modified in some way, to tackle other problems of a different nature.

- How did your experience of problem solving in Block 5 help you to solve problems of quite different kinds in this block?
- How did you need to adapt your problem-solving strategy for the different circumstances?

**Classifying** In the course you have seen many examples of situations where we have put things into categories or classes. Pick some examples of classification from Block 8, and consider the following questions:

- What is involved in classifying things?
- How and when do you use classification systems?
- What are the advantages of working with classification systems?

### *Transferability of techniques*

You have been asked in some of the activities in this block to note down your technique or strategy for tackling a particular task. For example, you have thought about your strategies for deciding what happens when chemical equilibrium is disturbed, for analysing the structure of organic compounds, and for predicting the products of organic reactions. These strategies relate to specific tasks, but the idea of formulating strategies, so that you have them at your fingertips ready for use, applies more generally. At present your record of such techniques is probably distributed in various places in your Study File notes. In this part of the activity you will consider how you can access your records of these techniques so that you can transfer them to new situations.

First decide how you would prefer to store your collection of techniques and strategies. This could be anything from creating a separate file with notes on the techniques, to making an index and deciding where to store it so that you know where to find existing notes

Second, decide which techniques you are going to keep a record of. Start with those that have been introduced in this block, and then consider other chemistry techniques you used in Block 6 (such as how to calculate empirical formulae). You may like to do something similar for techniques introduced in other blocks.

Third, make sure you have a record of your techniques and strategies in a form you can refer to, and understand, later.

### *Transferability of information: synthesizing information from different sources*

In earlier parts of the course you often had to pull together information from different sections of the block you were studying. In the second half of the course, you will also need to look back to previous blocks to remind yourself of information introduced earlier. For example, while studying this block you probably needed to refer to Block 6 to remind yourself of chemistry ideas introduced there. In Activity 17.1 you had to draw on information from Block 2 and the article in Appendix 2, as well as from various parts of Block 8. In doing this, you are developing two important skills: you are transferring scientific information from one context to use it in a different context, and you are *synthesizing* — drawing on information from a variety of sources, making connections, and putting it together in a new form to satisfy a specific requirement.

- Note down the ways in which you would locate information on specific topics from the course material and from elsewhere
- Having located the information, how would you make a record of what you found?
- Having gathered the information together, how would you synthesize it — put it all together?



## Comments on activities

### Activity 3.1

The electron configurations are shown in Table 3.1.2. From boron (atomic number 5) to neon (10), the 2p sub-shell is progressively filled. Figure 3.3 shows that, after this, the sub-shell of next higher energy is 3s, followed by 3p then 4s. The 3s sub-shell accommodates two electrons, taking us to magnesium (12), and then the filling of the 3p sub-shell takes us from aluminium (13) to argon (18). The filling of the 4s sub-shell then spans the next two elements, potassium and calcium.

**Table 3.1.2** A completed version of Table 3.1.1. The electron configurations of atoms of the first 20 elements

Atom	Atomic number	Electron configuration
H	1	1s <sup>1</sup>
He	2	1s <sup>2</sup>
Li	3	1s <sup>2</sup> 2s <sup>1</sup>
Be	4	1s <sup>2</sup> 2s <sup>2</sup>
B	5	1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>1</sup>
C	6	1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>2</sup>
N	7	1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>3</sup>
O	8	1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>4</sup>
F	9	1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>5</sup>
Ne	10	1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>6</sup>
Na	11	1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>6</sup> 3s <sup>1</sup>
Mg	12	1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>6</sup> 3s <sup>2</sup>
Al	13	1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>6</sup> 3s <sup>2</sup> 3p <sup>1</sup>
Si	14	1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>6</sup> 3s <sup>2</sup> 3p <sup>2</sup>
P	15	1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>6</sup> 3s <sup>2</sup> 3p <sup>3</sup>
S	16	1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>6</sup> 3s <sup>2</sup> 3p <sup>4</sup>
Cl	17	1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>6</sup> 3s <sup>2</sup> 3p <sup>5</sup>
Ar	18	1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>6</sup> 3s <sup>2</sup> 3p <sup>6</sup>
K	19	1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>6</sup> 3s <sup>2</sup> 3p <sup>6</sup> 4s <sup>1</sup>
Ca	20	1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>6</sup> 3s <sup>2</sup> 3p <sup>6</sup> 4s <sup>2</sup>

### Activity 3.2

(a) According to Figure 3.9, rubidium (atomic number 37) is in Group I of the table with an outer electron configuration  $ns^1$ . It lies in Period 5, so  $n = 5$  and it will have the outer electron configuration  $5s^1$ . Likewise, radium (atomic number 88) is in Group II with an outer electron configuration  $ns^2$ , and as it lies in Period 7,  $n = 7$ . Its outer electron configuration is therefore  $7s^2$ .

(b) To find the full electron configuration of the rubidium atom, we must assign 37 electrons by filling up the sub-shells in the order given in Figure 3.7, remembering that s, p, d and f sub-shells have a maximum complement of 2, 6, 10 and 14 electrons, respectively. This gives  $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^1$ . For radium, we do the same with 88 electrons; this gives  $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^6 6s^2 4f^{14} 5d^{10} 6p^6 7s^2$ . The sub-shells of highest principal quantum number, with their occupancies, are  $5s^1$  for rubidium and  $7s^2$  for radium. These correspond exactly to the answers to part (a).

### Activity 3.3

This activity reinforced concepts in Sections 2 and 3, and these are summarized in Section 3.5. You may wish to read that summary again before studying Section 4.

### Activity 4.1

The main features observed in the video are summarized in Tables 4.1.3 and 4.1.4.

**Table 4.1.3** A completed version of Table 4.1.1. Properties of ionic compounds and molecular substances.

Property	Substance	Comments	Ionic or molecular
melting temperature	carbon disulfide	low, liquid at room temperature	molecular
	iodine	low, solid at room temperature	molecular
	sulfur	low (110 °C), solid at room temperature	molecular
	alkali metal halide	high	ionic
solubility in carbon disulfide	iodine	dissolves instantly, purple solution	molecular
	sulfur	dissolves	molecular
	sodium chloride	insoluble	ionic
electrical conductivity of melt	sulfur	non-conducting	molecular
	alkali metal halide	conducting	ionic
solubility in water	sodium chloride	dissolves	ionic
	sulfur	insoluble	molecular
structure of solid	iodine	I <sub>2</sub> molecules	molecular
	sulfur	S <sub>8</sub> molecules, puckered ring	molecular
	sodium chloride	exists as alternating Na <sup>+</sup> and Cl <sup>-</sup> ions	ionic

**Table 4.1.4** A completed version of Table 4.1.2. Summary of the properties of ionic compounds and molecular substances.

Property	Ionic compounds	Molecular substances
melting temperature	high	low
electrical conductivity of melt	good	poor
solubility in water	good	poor
solubility in carbon disulfide	poor	good
structure of solid	ions	molecules

### Activity 6.1

Tables 6.1.5–6.1.8 summarize the observations you should have made from the video.

**Table 6.1.5** A completed version of Table 6.1.1. The changes taking place in Reactions 1–3.

Reaction number	Observation
1	When oxygen is bubbled through the solution it changes from yellow to red to green. When the oxygen source is removed the solution changes back from green to red to yellow.
2	When the liquid is added to the beaker the solution emits light
3	When the chemicals are mixed the solution in the cylinder changes from colourless to orange to black. The same colour change occurs when the solutions in the beakers are mixed, but at different speeds

**Table 6.1.6** A completed version of Table 6.1.2. Energy changes taking place in Reactions 4–6

Reaction number	Energy changes observed
4	When the reactants were mixed, light was given out. The temperatures of the reactants and products were the same (about 18 °C), thus little heat was generated
5	When the aluminium was dipped in the solution in the pot, the electric motor started up. A gas was given off at the surface of the aluminium. When the copper ring was removed from the solution the motor stopped
6	When the two solids were mixed, they reacted to form a liquid. The solution cooled down (to ~20 °C) so that the pool of water around the bottom of the beaker solidified.

**Table 6.1.7** A completed version of Table 6.1.3 Reaction 7: the colour changes that take place on heating and cooling

Conditions	Colour at start	Chemicals present at start	Colour at end	Chemicals present at end
beaker of ice	violet	reactant and product	pink	reactant
beaker of hot water	violet	reactant and product	blue	product
<i>test-tubes are then swapped over</i>				
beaker of ice	blue	product	pink	reactant
beaker of hot water	pink	reactant	blue	product

**Table 6.1.8** The time taken for the colour change to occur in the iodine 'clock' reaction

Beaker	Concentration of reactants	Time/s
left-hand	highest	5
2nd from the left	high	8
centre	intermediate	13
2nd from the right	low	23
right-hand	lowest	54

### Speed of reaction

Towards the end of the video we examined the effect of temperature and concentration on the speed of a chemical reaction. The reaction we used was that of iodide ions,  $I^-$ , with peroxodisulfate ions,  $S_2O_8^{2-}$ , often called the iodine 'clock' reaction:



A fixed amount of another compound was added to all the flasks; this compound removed the iodine,  $I_2$ , as it was formed. However, the added compound was itself consumed in this process. As soon as sufficient iodine was formed to remove all of the added compound, then the iodine concentration built up to give the black colouration. Thus the colour change marked the time taken for the reactions in each flask to form the same fixed amount of iodine. Faster reactions will form this amount of iodine in less time than slower reactions.

In these experiments the solution went from colourless to black after different periods of time (Table 6.1.8). The results confirm that when the concentration of the reactants is reduced the reaction is slower and thus takes a longer time to form sufficient iodine for the colour change.

### Catalysts

Finally, the effect of a catalyst on the breakdown of hydrogen peroxide to give oxygen and water was demonstrated. Lead oxide and manganese dioxide were the best catalysts, i.e. they produced the fastest reaction; liver also produced a reaction but potato and iron oxide were very poor catalysts.

### Important points demonstrated in the video 'Features of reactions'

- 1 The majority of chemical reactions involve energy being released or taken in.
- 2 Some reactions are essentially irreversible and give only products.
- 3 Some reactions are reversible and can give a mixture of reactants and products.
- 4 Reactions occur at different speeds.
- 5 The speed of a reaction is dependent on temperature and can also depend on the initial concentration of reactants.
- 6 A catalyst speeds up a reaction without itself being consumed.



## Activity 6.2

(a) The information in the last column of Table 6.1 indicates that 45 000 kJ are released per kg of octane burned (octane is said to be the 'representative' compound for petrol), whereas 27 000 kJ are released per kg of ethanol burned (Question 6.5). So on a mass-for-mass basis, octane appears to be the better fuel — for each kilogram burned you get  $45\,000/27\,000 = 1.7$  times more energy released as heat. Combustion of both octane and ethanol gives rise to the emission of carbon dioxide — a greenhouse gas — and water vapour

(b) Here are some of the questions about ethanol that you may have thought of:

How does ethanol compare with octane (or petrol) on a volume-for-volume basis?

How is ethanol produced? Is it a renewable fuel?

Does it produce other forms of pollution besides carbon dioxide?

Is it a safe fuel to transport and use?

Is it an economic fuel to produce and use?

(c) Below are lists of some benefits and drawbacks of ethanol as a fuel for cars.

### *Benefits of using ethanol as a motor fuel*

- According to the article, on a volume-for-volume basis ethanol is very similar to petrol (23 000 kJ per litre for ethanol as against 25 000 kJ per litre for petrol). This suggests that the same volume fuel tank will allow you to travel about the same distance with the two fuels. (The similarity between these values is puzzling. As the densities of ethanol and octane are similar ( $0.79\text{ g cm}^{-3}$  and  $0.70\text{ g cm}^{-3}$ , respectively) the energy per litre for these two fuels should differ by almost as large a factor as the energy per kilogram. Either octane is not 'representative' of petrol as far as energy content is concerned, or there is a mistake in the value quoted for the energy per litre of petrol.)
- It is a biomass fuel. So it is renewable, and its use preserves fossil fuel reserves.
- It is a so-called oxygenated fuel, so it produces less pollution when it burns.
- Plants take in carbon dioxide in photosynthesis, so although using ethanol as a fuel produces carbon dioxide, this is offset by the carbon dioxide absorbed from the atmosphere as the sugar cane (used to produce the ethanol) is growing.
- The article concludes that 'ethanol would seem to offer the best combination of convenience and safety for any liquid fuel'.

### *Drawbacks of using ethanol as a motor fuel*

- On a mass-for-mass basis, ethanol is not as good as petrol. For each kilogram of fuel burned, petrol releases roughly 1.7 times as much energy in the form of heat as ethanol, so you require a greater mass of ethanol to get you a certain distance. (If our figures are correct, ethanol requires a bigger fuel tank.)
- A large area of land is required to grow biomass for fuel production. The article tells us that 8% of Brazil's cultivated land was occupied by sugar cane for ethanol in 1990, and that an area one-third that of Wales would be needed to grow plants to produce the fuel used for transport in the UK. Turning over such a large area for this purpose must have environmental and social implications.
- It carries the additional problem of alcohol abuse.
- It cannot be produced at a price that is competitive with petrol.

Most of these points have been extracted from the *New Scientist* article. You should not have needed to read the article thoroughly to find this information, nor did you need to understand the whole article. You may well have spent longer reading this article than necessary because you were sidetracked into reading information that you found was interesting even though it was not relevant to the use of ethanol. Doubtless you came across some unfamiliar terms and concepts, but many of them will have been irrelevant to the ethanol story. In Activity 17.1 you will return to this article and will see how studying the later sections of this block helped you to understand some of these terms.

You may have followed the advice at the end of Box 6.2.1 about reading critically. Here is one student's response to the bullet points in the box:

I looked at Block 8 and thought about the use of ethanol as a fuel before reading the article, so I was able to compare my prior knowledge with what the article was saying

There were some technical words in the article which I didn't understand, but I think that I managed to get the gist of the argument as it related to ethanol. I didn't really understand Box 1 'Fuels from natural fats' at all, but this wasn't relevant anyway.

I was annoyed that the article said that ethanol is safe, but didn't explain this further.

I didn't spot any errors in the article, but I wouldn't have expected to as I didn't know much about the subject before starting to read the article.

## Activity 7.1

### Task 1

Here are a student's comments on this task

I need to decide what substances I'm going to test, what bits of equipment I'm going to use, how I'll carry out the tests, and how I'm going to record my results.

*What substances shall I use?* The notes in the Study File give quite a few suggestions. I've got all of the things listed, except for sparkling mineral water and bicarbonate of soda, so I'll test all of those I've got. That certainly gives me some solutions that are fairly acid — lemon juice and vinegar — and I think that washing soda is quite alkaline, so I should have quite a range. I'll also try cola, and I've got an opened bottle of white wine in the fridge so I'll try that too.

*What equipment shall I use?* The indicator papers are the vital things; there aren't many of them so I'll take the advice in the notes to cut them in half lengthwise. I've got plenty of yoghurt pots saved for recycling, so I'll use them to put the substances or solutions in. I probably ought to wash them out first, since I'm not usually very careful about washing the things that I recycle. And I'll use a permanent marker pen to note the contents on each pot. The only other things that I can think of that I need are a few teaspoons, and some paper towels or rags for mopping up drips and spills, and drying the pots and spoons. And that makes me think that the draining board in the kitchen is the best place to do this work.

*How will I do the tests?* For the liquids I can just pour a very small amount into a pot and dip a pH paper into it. What about soap and washing soda, which are solids? I'll have to dissolve them in water, but how much water? I guess the best thing to do is so make a saturated solution of each of the solids — put a teaspoonful in a pot and add a few spoonfuls of water, and stir it around for a while; as long as there's still some solid there the solution will be saturated. But does the amount of water make any difference? Presumably it must — the more water I add, the less concentrated the substance will be, so presumably the smaller the concentration of hydrogen ions. It would be worth checking this by measuring some of the solutions and then diluting them and measuring them again to see if there is a change in hydrogen ion concentration.

*How will I record the results?* A table is the obvious way, with columns for material tested, pH read from the cover of the indicator paper book, and hydrogen ion concentration from Table 7.1.1. And it would be useful to have a column for comments

### Task 2

Some of the hydrogen ion concentrations measured by a member of the course team are given in Tables 7.1.4 and 7.1.5. Do bear in mind that your solutions may not have the same concentrations as these and so you may have different values (though not too different). Also, you probably found that often the colour did not match any of those in the key exactly and you had to make a judgement as to which one or two it was closest to. This subjective element would mean that people testing identical solutions with identical papers may still come up with slightly different values.

**Table 7.1.4** A completed version of Table 7.1.2 Results of measuring the hydrogen ion concentration of household solutions

Solution	pH	Approximate concentration of hydrogen ions/mol litre <sup>-1</sup>	Comments
tap water	7–8	$1 \times 10^{-8}$ to $1 \times 10^{-7}$	
freshly boiled tap water	7	$1 \times 10^{-7}$	
sparkling mineral water	5–6	$1 \times 10^{-6}$ to $1 \times 10^{-5}$	
lemon juice	2	$1 \times 10^{-2}$	
vinegar	3–4	$1 \times 10^{-4}$ to $1 \times 10^{-3}$	
bicarbonate of soda	9–10	$1 \times 10^{-10}$ to $1 \times 10^{-9}$	
washing soda	10–11	$1 \times 10^{-11}$ to $1 \times 10^{-10}$	
household bleach	9	$1 \times 10^{-9}$	difficult to tell; took colour out of paper
washing-up liquid	8	$1 \times 10^{-8}$	paper colour masked by liquid colour
hair shampoo	5	$1 \times 10^{-5}$	paper colour masked by liquid colour
Flash cleaner	8–9	$1 \times 10^{-9}$ to $1 \times 10^{-8}$	

**Table 7.1.5** A completed version of Table 7.1.3 Results of measuring the effect of dilution on hydrogen ion concentration

Substance	Undiluted sample		Diluted 10-fold		Diluted 100-fold	
	pH	Hydrogen ion concentration /mol litre <sup>-1</sup>	pH	Hydrogen ion concentration /mol litre <sup>-1</sup>	pH	Hydrogen ion concentration /mol litre <sup>-1</sup>
washing soda	10–11	$1 \times 10^{-10}$ to $1 \times 10^{-11}$	10	$1 \times 10^{-10}$	9	$1 \times 10^{-9}$
washing-up liquid	8	$1 \times 10^{-8}$	7	$1 \times 10^{-7}$	7	$1 \times 10^{-7}$
lemon juice	2	$1 \times 10^{-2}$	3	$1 \times 10^{-3}$	4	$1 \times 10^{-4}$

### Task 3

(a) The higher the hydrogen ion concentration the more acidic the substance. For example, you know from Section 7.3 that lemon juice and vinegar are acidic and these have the highest (least negative powers of ten) hydrogen ion concentrations. Interestingly 'caustic' substances, such as washing soda, have very low hydrogen ion concentrations.

(b) Most personal washing materials which involve skin contact, such as soaps and shampoos, have hydrogen ion concentrations in the range  $1 \times 10^{-6}$  mol litre<sup>-1</sup> to  $1 \times 10^{-8}$  mol litre<sup>-1</sup>. Household cleaners and dishwasher liquids have lower hydrogen ion concentrations in the range  $1 \times 10^{-8}$  mol litre<sup>-1</sup> to  $1 \times 10^{-11}$  mol litre<sup>-1</sup>. If you tried fabric conditioner you probably found it has a relatively high hydrogen ion concentration.

(c) With the acidic solutions, dilution by a factor of 10 reduces the hydrogen ion concentration of the solution by up to a factor of 10. Dilution by a factor of 100 again reduces the hydrogen ion concentration. Dilution of the solutions with low hydrogen ion concentrations actually increases the hydrogen ion concentration! You will see why in Section 9.

### Task 4

Here are the comments from a student after completing the investigation:

My ideas in Task 1 were pretty much the same as the instructions, except I didn't think about making saturated solutions from all of the solids — I would have just dissolved an arbitrary amount in water. Also I didn't think about investigating what happens when more water is added to the solutions, though that seemed an obvious next step once it was suggested<sup>1</sup>

For some of the liquids I used their lids to pour a little liquid into for testing, which saved me a lot of fussing with yoghurt pots, though I still had to rinse the lid afterwards. In the dilution tests, I knew that a teaspoon was about 5 ml so I did all the dilutions in a measuring jug — 1 teaspoonful diluted to 50 ml — then tested. Then I diluted this solution to 500 ml and tested. This again saved time.



After I'd finished the tests, I thought of several other things to test, and I wished that I had thought more carefully about what I was going to use. I wonder whether the liquid that I use for cleaning silver is very acidic, and I also wonder about fabric conditioner. The other thing that I now want to know is what the hydrogen ion concentration of distilled water is.

So I guess that I was quite pleased with how the experiment worked out. I think that I did well to think of using the bottle lids, and of the method of diluting the liquids. The only minus points were that I should have thought a bit more about the experiment initially — could probably have thought of the dilution experiment myself — but time was short, and I wanted to get going! So the lessons I'm taking away from this are that it's worth looking for my own ways to improve on the instructions for the experiment — I don't need to assume that the OU has specified the best way — and that it would be useful to devote a bit more time to the initial 'thinking' stage.

Note that we gave you detailed instructions in Task 2 so that you would not waste any of your valuable time and because the number of indicator strips was limited. If we had not done so, you would probably have achieved the same results, but it may have taken somewhat longer. Also note that when you are evaluating your performance, it is as important to notice what you did well and why it was done well, as to identify what you can improve on another time.

### **Activity 8.1**

#### **Summary of 'Chemical equilibrium'**

##### *Introduction*

- 1 A reaction occurring in a closed container at constant temperature and pressure eventually reaches a fixed composition known as the equilibrium composition.
- 2 At equilibrium, the proportions of the various chemicals present are fixed but individual molecules are continually undergoing chemical change from reactants to products and back.
- 3 For the same temperature, pressure and proportions of the chemicals involved, the equilibrium mixture for a given reaction is the same whether you start with the compounds on the left of the equation (as written) or those on the right or a mixture of chemicals from each side.

##### *Effect of pressure*

- 4 For reactions involving gaseous molecules, it is possible to alter the pressure without adding or removing any chemicals. If there are more moles of product molecules than reactant molecules in the equation of the reaction, then increasing the pressure in this way will decrease the proportion of product in the equilibrium mixture.
- 5 If there are more moles of reactant molecules than product molecules in the equation of a reaction involving gaseous molecules, then increasing the pressure will increase the proportion of product in the equilibrium mixture.
- 6 The effects of changing pressure are examples of a more general principle known as Le Chatelier's principle:

When a system in equilibrium is subject to an external constraint, the system responds in a way that tends to oppose the effect of the constraint.

##### *Effect of temperature*

- 7 If heat is released into the surroundings when a reaction takes place (that is the reaction is exothermic), then performing the reaction at an increased temperature decreases the proportion of product in the equilibrium mixture.
- 8 If heat is absorbed from the surroundings when a reaction takes place (that is the reaction is endothermic), then increasing the temperature at which the reaction takes place increases the proportion of product in the equilibrium mixture.
- 9 The effects of changing temperature are also examples of Le Chatelier's principle.

### Effect of concentration

- 10 For reactions involving ions in solution, increasing the concentration of a reactant will cause there to be more product in the equilibrium mixture.
- 11 Conversely, if the concentration of a product is increased there will be an increase of reactant in the equilibrium mixture.
- 12 The effects of changing concentration are further examples of Le Chatelier's principle.
- 13 A graph of the concentrations of products multiplied together plotted against the concentrations of reactants multiplied together gives a straight line. The gradient of the line is known as the equilibrium constant  $K$ , and is different for different reactions.

### Activity 8.2

In the instructions for this activity, we deliberately didn't tell you whether or not to follow your problem-solving strategy from Block 5 step by step. The answers produced by two students are shown below. Both are completely correct, and show careful thought about the problem, but Student A (Table 8.2.1) has followed the strategy from Block 5 Activity 4.1 step by step, whereas Student B used a less rigid approach to problem solving.

**Table 8.2.1** Answer to Activity 8.2 produced by Student A.

1	Read the question	
2	Note down what I have to calculate and what I am given	Told the equation for dissociation of iodic acid and that $K = 0.17 \text{ mol litre}^{-1}$ at $25^\circ\text{C}$ . Asked to find $[\text{HIO}_3(\text{aq})]$ when $[\text{H}^+(\text{aq})] = 0.1 \text{ mol litre}^{-1}$ at $25^\circ\text{C}$ .
3	Think what concepts are involved	<p>The question obviously involves equilibrium constant, and Equation 8.15 with X replaced by <math>\text{IO}_3^-</math>. I know everything in this equation apart from <math>[\text{HIO}_3(\text{aq})]</math> (which I am trying to find) and <math>[\text{IO}_3^-(\text{aq})]</math>.</p> <p>The fact that I don't know <math>[\text{IO}_3^-(\text{aq})]</math> made me think that I was stuck. But Block 8 Section 8.3.2 helps me deduce that for every <math>\text{HIO}_3</math> molecule that dissolves, one <math>\text{H}^+(\text{aq})</math> and one <math>\text{IO}_3^-(\text{aq})</math> enter solution, i.e. <math>[\text{IO}_3^-(\text{aq})] = [\text{H}^+(\text{aq})]</math></p>
4	Recall appropriate equation(s)	$[\text{IO}_3^-(\text{aq})] = [\text{H}^+(\text{aq})]$ $K = \frac{[\text{H}^+(\text{aq})][\text{IO}_3^-(\text{aq})]}{[\text{HIO}_3(\text{aq})]}$
5	Combine equations and rearrange to solve for required quantity	<p>With <math>[\text{IO}_3^-(\text{aq})] = [\text{H}^+(\text{aq})]</math> and rearranging for <math>[\text{HIO}_3(\text{aq})]</math>, this gives:</p> $[\text{HIO}_3(\text{aq})] = \frac{[\text{H}^+(\text{aq})]^2}{K}$
6	Substitute values into the equation and calculate the answer	$[\text{HIO}_3(\text{aq})] = \frac{[\text{H}^+(\text{aq})]^2}{K} = \frac{(0.1 \text{ mol litre}^{-1})^2}{0.17 \text{ mol litre}^{-1}}$ <p>so <math>[\text{HIO}_3(\text{aq})] = 0.06 \text{ mol litre}^{-1}</math> to one significant figure</p>
7	Check unit of answer	The unit is $\text{mol litre}^{-1}$ as expected
8	Check number of significant figures in the answer	$[\text{H}^+(\text{aq})]$ given to one significant figure, so answer should be given to one significant figure
9	Check that the answer is reasonable	The concentration of undissociated iodic acid is not significantly less than the concentration of $[\text{H}^+(\text{aq})]$ in the equilibrium mixture. The equilibrium position, therefore, does not lie either well to the left or well to the right of the equation describing the dissociation (Equation 8.2.1). This agrees with value of $K$ ( $0.17 \text{ mol litre}^{-1}$ ), which is not greatly different from $1.0 \text{ mol litre}^{-1}$ .

Student B

*Start by thinking about what I already know, and how I am going to use this to find the answer.*

I'm told the equation for dissociation of iodic acid and that  $K = 0.17 \text{ mol litre}^{-1}$  at  $25^\circ\text{C}$ .

I'm asked to find  $[\text{HIO}_3(\text{aq})]$  when  $[\text{H}^+(\text{aq})] = 0.1 \text{ mol litre}^{-1}$  at  $25^\circ\text{C}$

$$K = \frac{[\text{H}^+(\text{aq})][\text{IO}_3^-(\text{aq})]}{[\text{HIO}_3(\text{aq})]}$$

I know everything in this equation apart from  $[\text{HIO}_3(\text{aq})]$  (which I am trying to find) and  $[\text{IO}_3^-(\text{aq})]$

I also know that for every  $\text{HIO}_3$  molecule that dissolves in water, one  $\text{H}^+(\text{aq})$  ion and one  $\text{IO}_3^-(\text{aq})$  ion enter into solution, i.e.  $[\text{IO}_3^-(\text{aq})] = [\text{H}^+(\text{aq})]$ .

This means that I can use the equation for  $K$  to find  $[\text{HIO}_3(\text{aq})]$ .

*Do the calculation.*

Substituting  $[\text{IO}_3^-(\text{aq})] = [\text{H}^+(\text{aq})]$  in equation for  $K$  gives

$$K = \frac{[\text{H}^+(\text{aq})]^2}{[\text{HIO}_3(\text{aq})]}$$

Rearranging gives

$$[\text{HIO}_3(\text{aq})] = \frac{[\text{H}^+(\text{aq})]^2}{K}$$

$$[\text{HIO}_3(\text{aq})] = \frac{(0.1 \text{ mol litre}^{-1})^2}{0.17 \text{ mol litre}^{-1}}$$

$$[\text{HIO}_3(\text{aq})] = 0.06 \text{ mol litre}^{-1} \text{ to one significant figure}$$

*Check that answer is reasonable*

The unit of the answer is  $\text{mol litre}^{-1}$  as expected. The value obtained for  $[\text{HIO}_3(\text{aq})]$  is reasonable — the concentration of undissociated iodic acid is roughly the same as concentration of  $[\text{H}^+(\text{aq})]$ , which is what I would expect when  $K$  is fairly close to  $1.0 \text{ mol litre}^{-1}$ .

Note that we have shown two somewhat different ways of solving problems here, and your method will probably be different again. This doesn't matter! There is no one correct method, and it is better that you use a method you are happy with rather than one we have imposed on you. You may like to continue using the method developed in Block 5, or you may like to develop your own method as the course progresses. Try to apply *your* strategy for problem solving to questions in the text, even when we don't remind you that they are 'problems'. Sometimes you will want to use your strategy as a guide; on other occasions all that will be necessary will be to think about the problem, do it, and then make sure that your answer is reasonable. Remember that problem solving often involves looking at a problem from a variety of angles until you can see your way through it.

A final point: note that you started with a skill learnt in Block 5 and then adapted it for use in Block 8 and beyond. In doing this you have successfully *transferred* a skill from one area of science to another.

### Activity 10.1

(a) When two tutors were asked to write out their strategy for answering this question the results were very different, and each tutor preferred their own strategy. This is not surprising and highlights why it is so important that you work out *your own* strategy, which works for you.

The tutors' combined strategy is outlined below. Check that your strategy covers all these points, and make sure, in particular, that you have thought about both the equilibrium position and the rate of reaction. You will find your strategy useful when doing other questions in this block and in later blocks, and in assignments.

*Strategy for problems involving equilibrium yields and rates of reactions*

- 1 Look at the equation for the reaction. Is the reaction endothermic or exothermic? Are there more moles of reactant or of product?
- 2 Remember the concepts to apply.

For equilibrium — Le Chatelier's principle; for rates — getting particles to bump into each other with enough energy to react. It may be helpful to express these concepts in your own words as a reminder:

Le Chatelier's principle says that if a system in equilibrium is subjected to a stress, the system tends to react in such a way as to oppose the effect of the stress; reactions are faster if there are more encounters between particles and if the reactant molecules meet with more energy

- 3 Apply the concepts to the problem

For equilibrium yield:

(i) Effect of pressure: if the reaction involves one or more gases, look at the equation to see if there are more or fewer moles of gaseous reactant molecules than product molecules. Remember that Le Chatelier's principle tells us that increasing the pressure favours the side of the reaction with fewer moles.

(ii) Effect of temperature: is the reaction exothermic or endothermic? Remember that Le Chatelier's principle tells us that increasing the temperature favours the reaction moving in the direction that is endothermic

(iii) Is there any other constraint on the equilibrium? (Is there a change in concentration for example?)

(iv) Effect of a catalyst: remember that catalysts do not affect the equilibrium yield.

For rates of reaction

(v) Effect of temperature: remember that all reaction rates increase when the temperature increases

(vi) Effects of concentration and pressure: increasing these can increase encounter rates and therefore increase reaction rates

(vii) Effect of a catalyst: remember that appropriate catalysts increase reaction rates.

(b) Now we shall use this strategy to answer each part of the question in turn.

- 1 Look at the equation for the reaction. Is the reaction endothermic or exothermic? Are there more moles of reactant or of product?

The thermochemical equation for the reaction was given in the question:



Since the enthalpy change is negative, the forward reaction is exothermic. There are more moles of reactant (7) than of product (4).

- 2 Remember the concepts to apply.

Le Chatelier's principle and collisions of molecules (as usual).

- 3 Apply the concepts to the problem.

For equilibrium yield:

(i) Effect of pressure: there are seven moles of reactant molecules and four moles of product molecules, so increasing the pressure increases the equilibrium yield.

(ii) Effect of temperature: the reaction is exothermic in the forward direction, so the equilibrium yield of product will be less at higher temperature.

(iii) Any other constraints? No.

(iv) Effect of a catalyst: none, as is always the case!



For rates of reaction:

(v) Effect of temperature: the increased temperature will increase the rate of reaction (as is always the case).

(vi) Effect of pressure: raising the pressure may increase the rate.

(vii) Effect of a catalyst: using a catalyst will increase the rate of reaction.

Note that we have laid out the answer here as a series of steps that correspond to the strategy outlined above. In practice, we would not explicitly write out all of the headings and words as in this answer. However, it is useful to go through the steps in a logical order when tackling a question like this to make sure that you have considered all of the factors.

Note that the temperature at which an exothermic process operates has to be a compromise between the requirements of high equilibrium yield (low temperature) and fast rate (high temperature). In this case there is an additional factor: if the temperature is too low, liquid water rather than water vapour will be present. High pressures will increase the yield but require special plant, and so economic factors may come into play. A catalyst is used in this process partly to avoid other reactions that may take place. The catalyst increases the rate of the desired reaction more than those of other reactions.

### Activity 11.1

#### Putting statements in a logical order

##### Case 1

An aqueous solution of an ionic compound conducts electricity (B) *because* an ionic compound is made up of ions (C) *and* in aqueous solution the ions are free to move around (A).

{This has to be the order since neither Statement A nor Statement C is explained by the other statements, whereas Statements A and C are needed to explain B.}

##### Case 2

The pH of a  $1.0 \times 10^{-2}$  mol litre<sup>-1</sup> aqueous solution of HCl is 2 (C) *because* HCl is a strong acid (A) *and* when the concentration of hydrogen ions in a solution is  $1.0 \times 10^{-n}$  mol litre<sup>-1</sup> then the pH is  $n$  (B).

{This is the only order that makes sense since statements B and C are not explained by either of the other statements. Note that there are certain assumptions made within Statement A that result from the definition of a strong acid. This perhaps becomes clearer if we expand Statement A a little. HCl is a strong acid, thus it dissolves completely into H<sup>+</sup>(aq) and Cl<sup>-</sup>(aq) ions such that a  $1.0 \times 10^{-2}$  mol litre<sup>-1</sup> aqueous solution of HCl has a hydrogen ion concentration of  $1.0 \times 10^{-2}$  mol litre<sup>-1</sup>.}

##### Case 3

Increasing the overall pressure leads to an increased equilibrium yield of ammonia (A) *and* increasing the temperature leads to a reduction in the equilibrium yield of ammonia (C) *because* Le Chatelier's principle states that when a constraint is applied to a system in equilibrium, the position of equilibrium will move in the direction that opposes the effect of the constraint (B).

{Here B is likely to be the explanation because it is a hypothesis rather than an observation such as statements A and C.}

##### Case 4

The electron configuration of rubidium is  $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 5s^1$  (B) *and* the outermost electron is easily removed (C), *which explains why* rubidium reacts violently with water (A).

{As you saw in Block 6, the alkali metals react violently with water. These Group I metals have an outer electron configuration  $ns^1$  and the outer electron is easily removed.}

### Identifying the best hypothesis to explain an observation

#### Case 5

C is the best explanation. Statements A and B refer to properties of the element bromine that have nothing to do with bond dissociations, which are always endothermic.

#### Case 6

B is the best explanation. Statement A just confirms that the compounds contain ions, and C explains why the compounds are ionic but not why they dissolve in water.

#### Case 7

C is the best explanation. Elements with similar electronegativities form molecular substances which have low boiling temperatures (Activity 4.1). Statement A just tells you how ammonia is made and B says something about its reaction with water, but nothing about whether it is a gas at 25 °C.

### Identifying the flaws in an argument

#### Case 8

A is incorrect; concentrations can be quoted for any volume of solution. C is correct (magnesium chloride is an ionic compound) but does not explain why the statement is wrong. B is the best explanation of why the statement is wrong, because if two chloride ions are present in the formula unit of magnesium chloride, the concentration of chloride ions will be 0.2 mol litre<sup>-1</sup>.

#### Case 9

B and C are both incorrect. The pH reflects the concentration of only hydrogen ions and sodium hydroxide is a base not an acid. A is the best explanation of why the statement is false because if OH<sup>-</sup> ions are added the concentration of hydrogen ions will decrease and the pH will increase.

#### Case 10

B and C have nothing to do with the original statement being wrong. C is also incorrect because covalent bonds not hydrogen bonds are made and broken when octane burns. A is correct and it explains why the hydrogens in octane do not form hydrogen bonds.

### Activity 12.1

(a) All the names end in -ane

(b) As you progress from the top to the bottom of the second column, the numbers of carbons and hydrogens in the molecular formula increase. In particular, there is a difference of one carbon atom and two hydrogen atoms between adjacent molecules. The next two columns show the same trend. As you go down the third column each

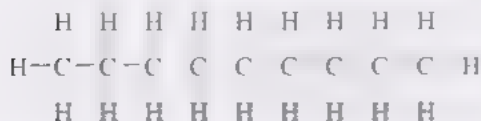
structure has an extra  $\begin{array}{c} \text{H} \\ | \\ \text{---}\text{C}\text{---} \\ | \\ \text{H} \end{array}$  in the structural formula, in comparison to the one

above it. Similarly, the abbreviated structural formula contains an extra  $\text{---CH}_2\text{---}$ .

(c) As you go down the fifth column, the boiling temperature increases. However, it does not increase by the same amount each time; the *difference* between boiling temperatures of adjacent molecules gets smaller and smaller. The increase in boiling temperature is due to the fact that London interactions between molecules become stronger as the relative molecular mass increases (Sections 7.2.1 and 12.2).

(d) The next member after octane has a molecular formula with one extra carbon atom and two extra hydrogen atoms, thus the molecular formula is  $C_9H_{20}$ . The structural

formula has an extra  $\begin{array}{c} \text{H} \\ | \\ \text{---C---} \\ | \\ \text{H} \end{array}$  giving



and the abbreviated structural formula has an extra  $\text{---CH}_2\text{---}$ , giving:

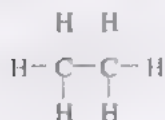


This linear-chain hydrocarbon is called nonane. {Because the boiling temperatures increased by  $29^\circ\text{C}$  and  $28^\circ\text{C}$  in going from hexane to heptane and from heptane to octane, it would be reasonable to predict an increase of  $27^\circ\text{C}$  to  $153^\circ\text{C}$  for nonane; its boiling temperature is actually  $151^\circ\text{C}$ .}

## Activity 12.2

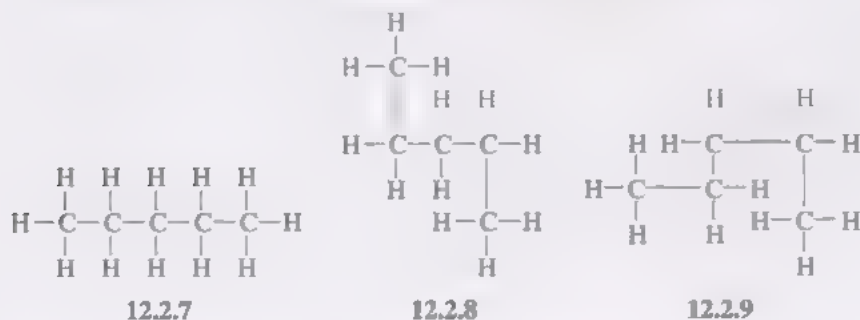
Summary of 'The shapes of molecules' section of 'Organic molecules'

- 1 The four bonds of a carbon atom do not all lie in the same plane pointing to the corners of a square, as we represent them in two dimensions, but point to the corners of a three-dimensional tetrahedron.
- 2 Rotation about single bonds is easy, so two structures may look different, but rotation about carbon-carbon bonds may reveal that they are identical. When examining whether two molecules are isomers or are identical we must always consider rotations about a single bond.
- 3 Although when we draw a structural formula such as



we seem to indicate that the hydrogens pointing to the left or to the right are different from the hydrogens pointing up or down, in fact when we examine the more realistic three-dimensional representation we can see that all six hydrogens are indistinguishable.

- 4 When considering whether two-dimensional representations of molecules (structural formulae) represent the same molecule or isomers, we must concentrate on the order in which the atoms are joined and not the way they are represented on the paper. Thus, structures 12.2.7<sup>w</sup>, 12.2.8 and 12.2.9 are two-dimensional representations of the same molecule. Although they look different in two dimensions, the atoms in each structure are joined in the same order.



Now do part (b) of this activity *before* reading the comments below.

### Task 1

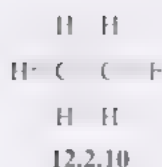
**12.2.1** and **12.2.2** are the same molecule, since all the bonds attached to a particular carbon are identical. In both, one carbon is bound to three hydrogens and one carbon, and the second carbon is bound to two hydrogens, one fluorine and one carbon. The two-dimensional representations look different because in **12.2.1** the fluorine points to the right but in **12.2.2** the fluorine points down. Manipulation of the three-dimensional representation using WebLab shows that the two structural formulae are identical

### Task 2

**12.2.3** and **12.2.4** are isomers. Each consists of a chain of three carbon atoms, but in **12.2.3** the fluorine is bonded to one of the end carbons, whereas in **12.2.4** the fluorine is attached to the middle carbon. These two structures cannot be interconverted by bond rotations. If you are unsure of this, open **12.2.3** and **12.2.4** in WebLab and use the Tile option in the Window menu to show the structures side by side.

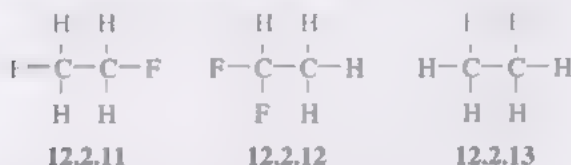
**12.2.5** is identical with **12.2.3** since the order in which the atoms are joined is the same. **12.2.6** is identical with **12.2.4** — one is drawn with a linear carbon backbone and the other is drawn with a bent carbon backbone, but in each case the fluorine atom is joined to the central carbon atom.

### Task 3



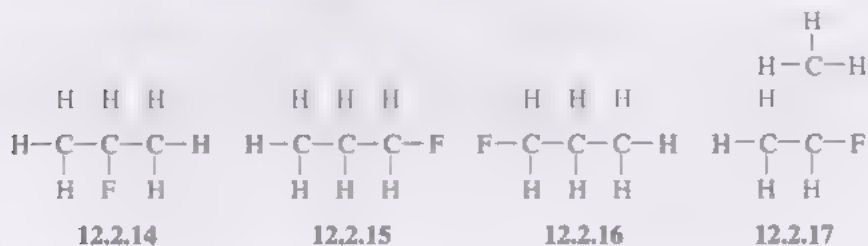
(a) There is only one way in which these atoms can be ordered, as shown in structure **12.2.10**

(b) There are two ways in which these atoms can be ordered, either with one fluorine on each carbon, **12.2.11<sup>W</sup>**, or with both fluorines on one carbon, **12.2.12**. As in the last task there are various ways of representing these molecules; for example **12.2.11** can also be represented as **12.2.13**. Although these structural formulae look different, the atoms are still joined in the same sequence.



### Task 4

This time there are two possibilities, shown as structures **12.2.14<sup>W</sup>** and **12.2.15<sup>W</sup>**. If you are unsure of this, you should open the appropriate files in WebLab and tile the two structures side by side. Structure **12.2.16** is the same as **12.2.15**, just the other way round, and **12.2.17** is the same as **12.2.14**



## Activity 13.1

(i) Hydrocracking involves the breaking down of hydrocarbons into smaller fragments. Hydrogen is supplied to ensure that alkanes are obtained. The atoms are also rearranged to give mainly branched-chain hydrocarbons.

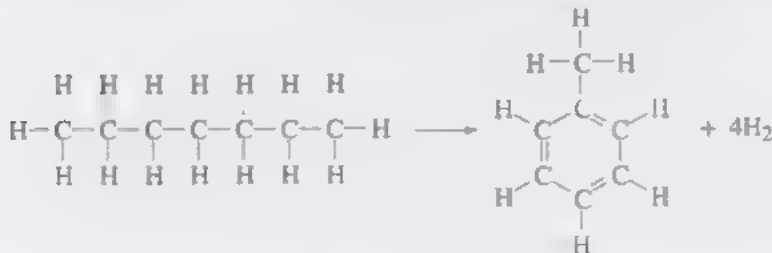


(ii) Catalytic cracking involves heating an alkane strongly *without added hydrogen*, in the presence of a zeolite catalyst, to give alkenes. A typical transformation for catalytic cracking is



One of the products is hydrogen, which can be used in hydrocracking.

(iii) Catalytic reforming involves converting the linear-chain alkanes in crude oil into aromatic compounds, cycloalkanes and branched-chain alkanes. For example:



(iv) Isomerization is carried out at 100–200 °C, using a platinum catalyst, and involves converting a compound into an isomer. For example:



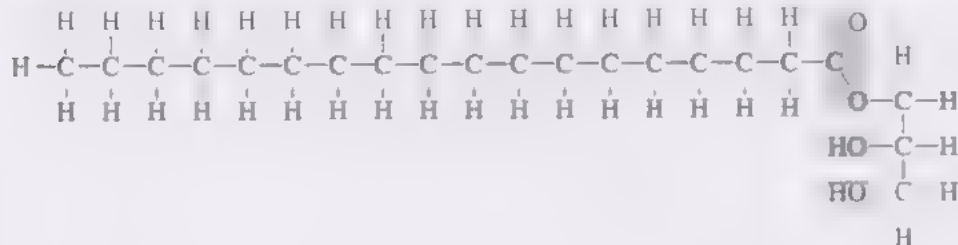
Hydrocracking and catalytic cracking are similar in that they are processes that involve large molecules being broken down into smaller ones. However, hydrocracking produces alkanes, which are saturated hydrocarbons, whereas catalytic cracking produces alkenes, which are unsaturated hydrocarbons. Both catalytic reforming and isomerization convert alkanes into compounds with similar relative molecular masses to the starting compounds. The processes differ in that hydrocracking uses hydrogen to give alkanes, whereas isomerization does not use hydrogen, and catalytic cracking and reforming actually form hydrogen. All of the processes require high pressure, high temperature and a catalyst, though this is not stated explicitly in the text in each case.

### Activity 14.1

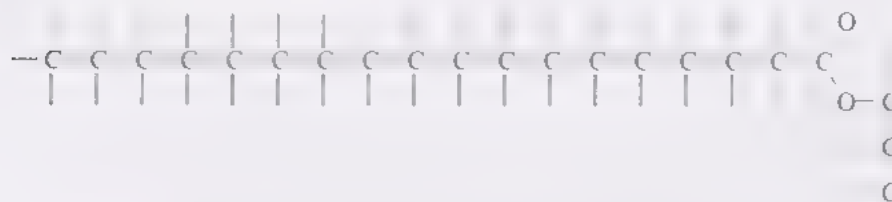
This activity provided an introduction to the functional group approach, and this approach to understanding organic molecules and their reactions will be explored in more detail in the rest of Section 14.

### Activity 14.2

(a) The glyceryl monostearate molecule contains an ester group and two alcohol groups.



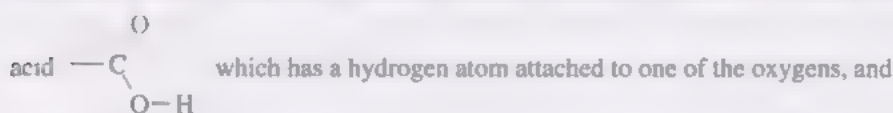
The molecule has a linear chain of 17 carbons attached to the ester group, and it also has a chain of three carbon atoms with an oxygen attached to each:



Note that the carbon that is part of the ester functional group is not counted as part of the linear chain of carbon atoms.

(b) When a S103 tutor was asked how she analysed the structure of this molecule she responded as follows:

When I look at a structure, I first focus on the functional groups. The way to spot functional groups is to look for double bonds, or atoms other than hydrogen and carbon. The functional groups that are important for S103 are in Appendix 1. It's important to make sure you've spotted all the atoms in a functional group. For example, an —OH could be an alcohol group, but it could also be part of a carboxylic acid, so I check to see if there is a double bond to oxygen on the carbon connected to the —OH group. Another possible confusion is between a carboxylic



an ester, where the corresponding oxygen is attached to another carbon atom. I usually circle the functional groups, or shade over them, to avoid counting them twice

Having identified the functional groups the next thing I do is to focus on the carbon atoms, and identify how many chains, or rings, of carbons are present, how many carbons are in each chain, and whether the chains are linear or branched. Glycerol monostearate has a linear chain of 17 carbons attached to the ester group, and it also has a chain of three carbon atoms with an oxygen attached to each. Then if there is more than one chain of carbon atoms in the molecule, I establish how the chains are joined together and how the groups are sited on the carbon chains. In glycerol monostearate, the two chains are joined together by an ester group. The —OH groups are on adjacent atoms of the three-carbon chain, next to the ester group.

One final thing that I often do is to check that the remaining valencies on the carbons are satisfied with hydrogens. This helps to confirm that there are no other functional groups that I've missed.

Here is a summary of this tutor's strategy:

- 1 Identify which functional groups are present;
- 2 Identify the saturated carbon chains;
- 3 Establish how the functional groups and chains are joined together.

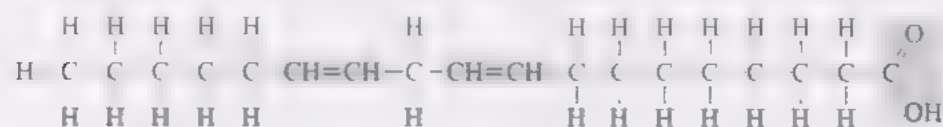
Your strategy may have been different from this — there is no unique way of analysing the structure of an organic molecule — but you should carefully compare your strategy with the tutor's, and modify your strategy if necessary.

*Please attempt part (c) of this activity before reading the following comments.*

(c) We will use the three steps of the tutor's strategy, summarized at the end of part (b), to analyse the structure of linoleic acid.

- 1 Identify which functional groups are present.

Here we can identify two carbon–carbon double bonds and a carboxylic acid group:





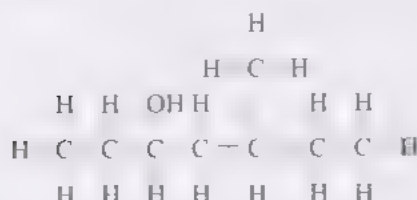
$$\text{C}-\text{C}-\text{C}-\text{C}-\text{C} \quad \text{C} \quad \text{C} \quad \text{C}$$
$$\text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} \begin{matrix} \text{O} \\ | \\ \text{OH} \end{matrix}$$
$$\begin{array}{ccccccc} \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \\ | & | & | & | & | & | & | \\ \text{H}-\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C}-\text{COOH} \\ | & | & | & | & | & | & | \\ \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \end{array}$$
$$\begin{array}{c} \text{O} \\ \parallel \\ -\text{C}- \\ | \\ \text{O} \end{array}$$
$$\begin{array}{ccccccc} & & & & & & \textcircled{0} \\ \textcircled{C} & \textcircled{C} & \textcircled{C} & \textcircled{C} & \textcircled{C} & \textcircled{C} & \\ & & & & & & \textcircled{0} \end{array}$$
$$\begin{array}{c} \text{O} \\ \parallel \\ \text{C}=\text{C}-\text{C}-\text{C}=\text{C} \\ \quad \quad \quad \backslash \\ \quad \quad \quad \text{O}-\text{C}-\text{C}-\text{C} \end{array}$$
$$\begin{array}{cccccccccccc} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{O} & & & & & \\ \text{H} & \text{C} & \text{C} & \text{C} & \text{C} & \text{C} & \text{C} & \text{H} & \text{H} & \text{H} & & \\ & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{O} & \text{C} & \text{C} & \text{C} & \text{H} & \\ & & & & & & & \text{H} & \text{H} & \text{H} & & \end{array}$$

C C C C C C C

$$\text{C}=\text{C}-\underset{\text{OH}}{\text{C}}=\text{C}-\text{C}-\text{C}$$
$$\begin{array}{c} \text{H} \\ | \\ \text{H}-\text{C}-\text{H} \\ | \\ \text{OH} \\ | \\ \text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C} \end{array}$$



Adding sufficient hydrogens gives the final structure:



#### Activity 14.4

There are no comments on this activity.

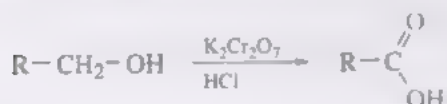
#### Activity 14.5

(a) This is an oxidation reaction, and the product is a carboxylic acid, **14.5.1<sup>w</sup>**.

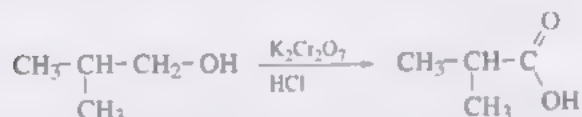
(b) The strategy used by a member of the course team is as follows:

*Identify the functional group(s) in the organic molecule(s).* In this case the only organic molecule, **14.5.2<sup>w</sup>**, contains an alcohol functional group.

*Next look up the reactions of the functional group(s).* Appendix 1 is a useful source of reference for the important reactions. So far you have learnt that alcohols undergo condensation reactions and oxidation reactions. Condensation reactions involve reaction with a carboxylic acid, which we don't have here. However, the oxidation reaction shown in Appendix 1 indicates that  $\text{K}_2\text{Cr}_2\text{O}_7$  oxidizes alcohols to carboxylic acids, so this is the appropriate reaction:



*Finally identify the hydrocarbon portions of the reactant(s), and copy them to give the product.* Comparing the alcohol in the question with  $\text{R}-\text{CH}_2-\text{OH}$ , we see that in this case R is  $\text{CH}_3-\text{CH}-\text{CH}_3$ , so we draw the product by replacing R with  $\text{CH}_3-\text{CH}-\text{CH}_3$ .



Compare your strategy with the one outlined above. It may be different — as usual, there is more than one way to tackle a problem! You may wish to combine the best points of the two approaches.

*Please attempt part (c) of this activity before reading the following comments.*

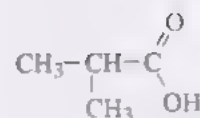
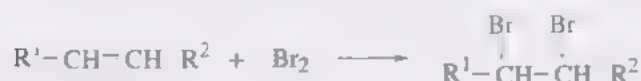
(c) We will again use the three-step strategy outlined in part (b).

*Identify the functional group(s) in the organic molecule(s).* In this case, the only organic molecule, **14.5.3<sup>w</sup>**, contains an alkene functional group.

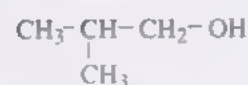
*Next look up the reactions of the functional group(s).* The only reaction of alkenes that you have learnt about so far is an addition reaction, and, as shown in Appendix 1, this has the general form:



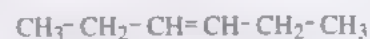
In this case, the reaction involves addition of bromine, so X and Y are both Br.



**14.5.1**

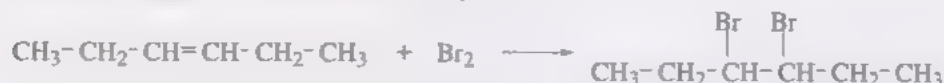


**14.5.2**



**14.5.3**

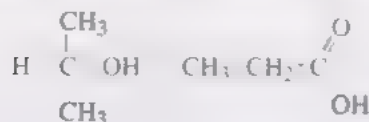
Finally identify the hydrocarbon portions of the reactant(s), and copy them to give the product. Comparing the alkene in the question with the general formula  $R^1-CH=CH-R^2$ , in this case  $R^1$  and  $R^2$  are both  $CH_3-CH_2-$ . So the product is drawn by replacing  $R^1$  and  $R^2$  with  $CH_3-CH_2-$ .



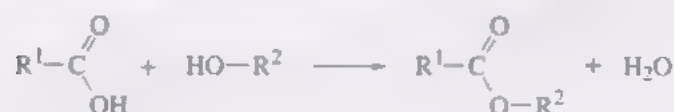
Please attempt part (d) of this activity before reading the following comments

(d) The same strategy works for this slightly more complicated reaction.

Identify the functional group(s) in the organic molecule(s). In this case there are two organic molecules, an alcohol and a carboxylic acid:

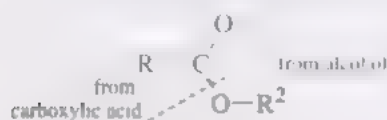


Next look up the reactions of the functional group(s). Appendix 1 shows that alcohols undergo condensation reactions with carboxylic acids:

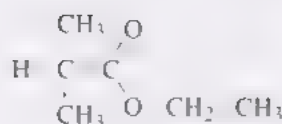
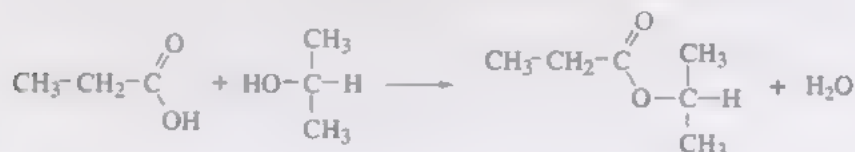


Finally identify the hydrocarbon portions of the reactant(s), and copy them to give the product. This is a little more complex because there are two hydrocarbon chains and two different places to put them. The general equation in Appendix 1 shows that the hydrocarbon portion of the carboxylic acid ends up attached to the carbon of the ester group and that the hydrocarbon portion of the alcohol ends up attached to the oxygen of

the ester. Another way of looking at this is that the  $R^1-\overset{\overset{O}{||}}{C}$  comes from the acid, and the  $-O-R^2$  comes from the alcohol:



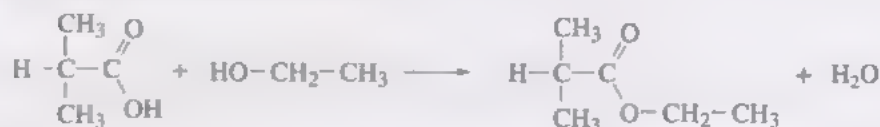
Since the hydrocarbon portion does not change during the reaction, once we have identified which hydrocarbon goes where, it is just a question of copying them down correctly. In this case  $R^1$  is  $CH_3-CH_2-$  and  $R^2$  is  $CH_3-CH-CH_3$ . So the reaction is:



14.5.4

14.5.4<sup>w</sup> is not formed in this condensation reaction. What are the carboxylic acid and the alcohol that would react to form this ester?

The reaction that forms this ester is:



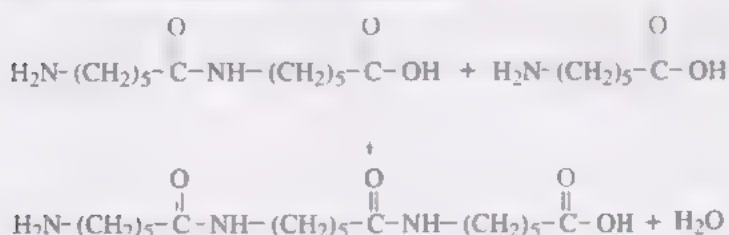
At various points during the rest of the block you will be asked to predict reactants or products, and we recommend that you use a similar strategy whenever possible. You will find that this strategy, and also your strategy for analysing the structure of organic molecules, will be useful when you meet functional groups again if you decide to study Block 9.

Your list will depend upon where you are studying and your knowledge of plastics. Some of the plastics you might have included are: nylon (polyamides), rubber, polythene, PVC (poly(vinyl chlorides)), PVA (poly(vinyl acetates)), acrylates (polyacrylates), acrylonitriles (polyacrylonitriles), polyesters, polypropylene, polystyrene, neoprene, Perspex (poly(methyl methacrylate)).

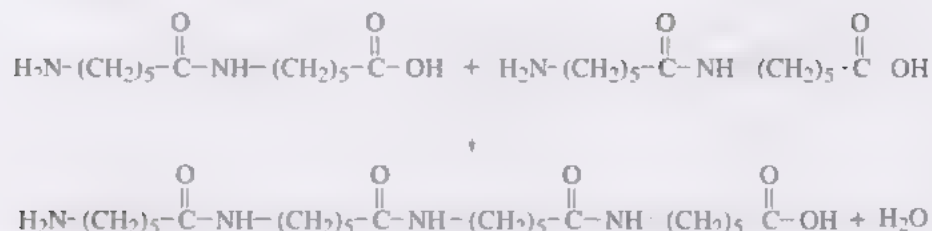
- a variety of densities;
- some are tough and others break easily;
- some are rigid and some are flexible;
- some are clear and some are coloured.

You may well have identified other plastics, and other properties of these plastics. These manufactured materials are members of a much larger group of materials, all of which are made of long chains of atoms, as you will see in Section 15.

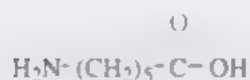
(a) To form a polymer we need a monomer that can form *two* covalent bonds to other monomers. This usually means we need a monomer with two functional groups. If the monomers are to be joined using a condensation reaction between an amine and a carboxylic acid to give an amide, then either the monomer should contain an amine and a carboxylic acid, as in 15.2.4 (the squiggly line is used to represent any chain of carbon atoms), or there should be a mixture of two monomers, one that contains two amine groups, as in 15.2.5, and another that contains two carboxylic acid functional groups, as in 15.2.6.



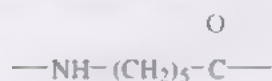
Alternatively small chains of molecules can react:



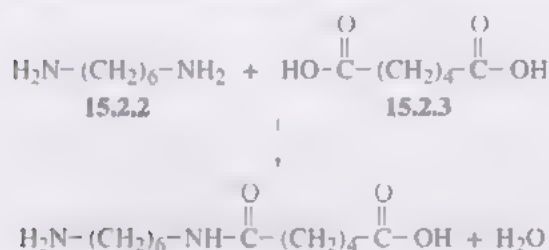
This process can continue with other monomer molecules building up a long chain. The product is the polyamide Nylon-6, so called because there are six carbon atoms in the monomer unit. The monomer is **15.2.1**:



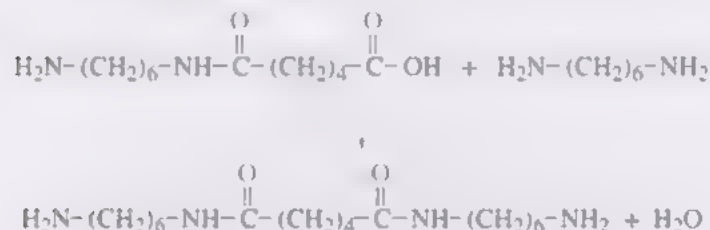
and the monomer unit is



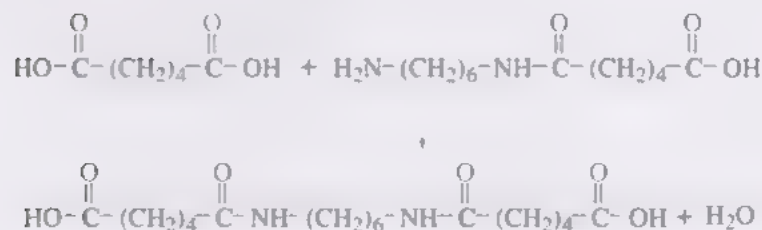
(ii) In this case, neither monomer can polymerize on its own, but the two types of monomer can react with each other. The diamine, **15.2.2**, can react with the dicarboxylic acid, **15.2.3**, via a condensation reaction:



This molecule contains amine and carboxylic acid groups at opposite ends, so it can react with either type of monomer:



or



Again the process can continue to give a long polymer chain. The product is the polyamide Nylon-6,6 so called because there are two monomers (**15.2.2** and **15.2.3**) each of which contains six carbon atoms.



### Activity 15.3

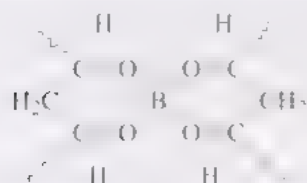
#### Task 1

You should find that Polymer A does not appear to flow readily. However, if you leave it for some minutes it will slowly flatten and 'relax'. (You may have seen this behaviour with childrens' 'silly putty'.) As the concentration of the stock borax solution is diluted with water the polymer formed becomes more fluid. Polymer B visibly flattens as you look at it. Polymer C flattens very quickly and is more like a liquid. However, if you compare Polymer C with the original glue it has changed. It leaves the sides of the cup easily and adheres to itself more. (It looks like the children's toy 'slime'.)

Borax has the formula  $\text{B(OH)}_3$ , and in water it forms  $\text{B(OH)}_4^-$  ions, via the equilibrium:

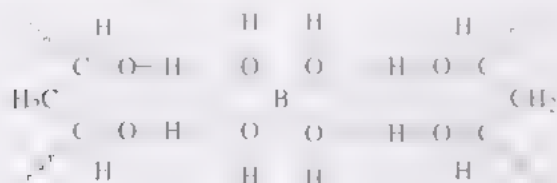


This  $\text{B(OH)}_4^-$  reacts with the alcohol groups on the poly(vinyl alcohol) polymer to form a three-dimensional network of boron–oxygen cross-links between the chains (the squiggly lines are used to represent the backbone chain of the polymer):



This means that the polymer chains can no longer slide over each other and the polymer becomes semi-solid. The higher the concentration of  $\text{B(OH)}_4^-$ , the more cross-links there are and the stiffer the polymer. Hence Polymer A is stiffer than Polymers B and C.

When there is a large amount of water present, instead of the links being via strong covalent boron–oxygen–carbon bonds, some of the bonds are with the  $\text{B(OH)}_4^-$  ion via weaker hydrogen bonds.



The resulting polymer, e.g. Polymer C, will then be less strongly cross-linked.

#### Task 2

The effect of adding water to each of the poly(vinyl alcohol)/borax polymers is summarized in Table 15.3.2. Polymer C will have the greatest number of weak hydrogen bonds and so its structure will be destroyed by being dissolved in hot water. The polymer that is, at least partly, more strongly bonded via covalent bonds (Polymer A), will withstand the boiling water although it will become less stiff as the molecules untangle.

**Table 15.3.2** A completed version of Table 15.3.1. Observations of the effect of water on the polymers.

Polymer	Cold water	Hand-hot water	Boiling water
A	no effect	no effect	becomes like slime but does not dissolve
B	no effect	softens slightly	appears to dissolve but could just be forming very thin slime
C	softens slightly	dissolves	dissolves

#### Task 3

All three polymers should become thinner when they are heated, though the effect is greatest for Polymer C for the same reason that it dissolves in boiling water (see Task 2).

#### Task 4

In order for boron–oxygen cross-links of any type to be formed, the equilibrium in Equation 15.3.1 will have to lie over to the right. However, the equilibrium can be manipulated to push it to the right, and so add boron–oxygen cross-links, or to the left, and so take away cross-links.

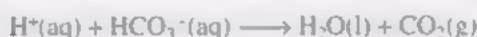
If you add acid and thus increase the hydrogen ion concentration, by Le Chatelier's principle, the system acts to reduce the concentration of hydrogen ions and so the equilibrium in Equation 15.3.1 is shifted to the left. This then also removes  $\text{B}(\text{OH})_4^-$  ions and thus removes the links between the chains and so the solid polymer is destroyed. This is why the polymer dissolves in vinegar or lemon juice, which are both acid

If you then add a base, washing soda, it removes hydrogen ions and the equilibrium shifts to the right to form more  $\text{B}(\text{OH})_4^-$  ions. A solid polymer, D, forms. You probably found that Polymer D was even stiffer than Polymer A, remaining 'domed' long after Polymer A had flattened out. Because more  $\text{B}(\text{OH})_4^-$  ions are formed when the equilibrium shifts to the right, Polymer D has more cross-links than Polymer A and so is the stiffest polymer of all. Likewise, if you make the original Polymer A in the presence of washing soda it will be very stiff.

- How could you check that the washing soda does not cause the poly(vinyl alcohol) glue to harden?
- If you add a teaspoonful of washing soda solution to the poly(vinyl alcohol) glue alone it should remain a liquid. However, if you then add a teaspoonful of borax solution you will form a stiff polymer like Polymer D.

#### Task 5

If you add alkaline sodium bicarbonate ( $\text{NaHCO}_3$ ) to the acidic solution of the polymer it reacts with the acid to form carbon dioxide:



As with the addition of washing soda (Task 4) this removes hydrogen ions and shifts the equilibrium to the right so the boron–oxygen cross-links are formed. However, the polymer is forming in the presence of carbon dioxide bubbles and hence encloses the bubbles to form an expanded foam, which has a much larger volume than that of the unfoamed polymer. Unfortunately, this polymer is a soft, flowing plastic so it will eventually collapse. A real foam plastic, such as expanded polystyrene, is made by blowing gas through the plastic as it forms but then the polymer sets hard while expanded.

#### Activity 17.1

(a) Among the terms that may not have meant much to you before studying the organic chemistry sections of Block 8, but which you should now understand, are the following: hydrocarbons, methane, ethane, propane, butane, ethanol, methanol, alcohols, esters. Also you can deduce that rape methyl ester must be an ester produced from rape seeds. You should also be familiar with the concept that heavier hydrocarbons are less volatile than lighter hydrocarbons, because of increasing London interactions, and you should have increased your knowledge of petrol, diesel, oil, leaded petrol and plastics.

There are probably some terms which still do not make much sense, such as triacylglycerides, though the structural formula probably gave you a good idea of what these are. (You'll meet these compounds if you decide to study Block 9, because they are the constituents of many fats and oils.) If there are points that you still don't understand, you may wish to refer to the Course Glossary or a dictionary, or to discuss your questions with other students, your tutor, colleagues or friends.

(b) Your criticisms of this letter might include some of the following.

- 1 Overall, this letter gives one side of a debate, and so misses some points completely. The author also has some facts wrong, and, in attempting to persuade, overstates his case.
- 2 He omits the important point that burning renewable fuels does not increase the amount of carbon dioxide in the atmosphere.
- 3 He avoids discussion of the importance of reducing air pollutants, such as carbon monoxide and ozone, in cities.
- 4 He overstates the case for petrol although there are considerable reserves of oil, it is still a finite resource.
- 5 He has some of the facts wrong: rapeseed is just one of the possible biofuels referred to in the article, and it suggested that an area *one-third* the size of Wales could grow sufficient *fodder beet* to fuel Britain's cars.
- 6 He advocates use of nuclear power to generate electricity without pointing out the significant environmental drawbacks.
- 7 He states that 'AGR stations produce 54.1 TWh  $y^{-1}$  of electricity'; the acronym AGR for advanced gas-cooled reactor, and the unit TWh  $y^{-1}$ , will not be familiar to most readers.
- 8 He draws a conclusion without taking all the relevant information into account. The facts about petrol being more economical to use than ethanol, and RME costing 24p per litre compared with petrol at 10p per litre need to be balanced by consideration of global economic consequences of increased concentrations of atmospheric carbon dioxide and of pollution in cities.

(c) There are a variety of points that you could include in a letter that was trying to present a more balanced argument.

- Oil reserves are a finite resource, and exploiting the remaining reserves is increasingly difficult.
- Oil should be used for the petrochemical industry, not burned as fuel.
- A wide range of different crops can be grown for biofuel.
- The importance of taking action to reduce air pollution, which is a growing problem in cities, and causes a variety of health problems resulting in increased expenditure on medical care.
- Use of biofuels does not increase carbon dioxide levels in the atmosphere. Increasing the proportion of carbon dioxide in the atmosphere is likely to upset the Earth's climate.
- Environmental impact needs to be taken into account, as well as the basic costs of different fuels.

If you had time, you could try to turn your list of points into a letter of response. For interest, we give one possible response below.

Dear Editor

Oz Tritch overlooked a number of important points and made several very misleading statements in arguing that we should not make more use of renewable fuels. In particular, he omits to point out that renewable fuels don't increase carbon dioxide levels in the atmosphere. The crops grown to provide renewable fuels actually absorb carbon dioxide from the atmosphere to achieve growth, and this carbon dioxide is merely recycled when the fuel is burned. So renewable fuels do not contribute to the greenhouse effect and global warming.

Your paper has published plenty of evidence in recent months that global warming is already affecting climate. Scientists have predicted that continued warming could lead to rises in sea-level as polar ice melts, and large areas of land could be inundated. We need to reverse the warming trend, and reducing the amount of fossil fuel burnt is therefore essential.

In addition, reserves of fossil fuels are limited, and so they should be used to provide the chemicals and pharmaceuticals invaluable in modern life rather than simply burned. The reserves may be sufficient for hundreds of years, but do we have the right to continue to use them at the current rate so that our descendants are deprived of access to these valuable resources?

Nearer to home, there are increased death rates in cities due to asthma or bronchitis at times of poor air quality. The solution to this problem must involve reducing air pollution, and the best way to do this is to find alternative cleaner fuels for our vehicles. It is true that electrically powered vehicles would reduce pollution in our cities, but we have to look at the consequences elsewhere. Nuclear power stations could provide the electricity required to charge vehicle batteries without generating greenhouse gases, but concerns about safety and the long-term environmental impact of the nuclear industry mean that this option is unlikely to be acceptable.

It is clear that if decisions about fuels are based on short-term economic grounds, petrol and diesel will continue to be used for vehicles. I would argue that we have to take a longer-term perspective, and take into account the impact of increasing use of fossil fuels on health and the environment. For all of these reasons, I think it is vitally important that we develop alternative and renewable forms of fuel.

Yours sincerely

If you actually wrote the letter that you planned in this activity, your approach would probably be different, and no doubt you have found various points to criticize in this sample letter. Looking critically at other people's work in this way will help you to judge the quality of your own work.

In the second half of *Discovering Science*, we want you to broaden your reflection on your learning and skills development, and to start to ask yourself 'How well did I do that?' To answer this question, you need to be able to judge between work that is well done, work that is adequately done, and work that is not done well enough. By learning how to criticize other people's work, you are equipping yourself to judge your own, in particular being able to identify the criteria on which you form your judgements. This is important because you will then be able to take appropriate steps to improve your own performance.

## Activity 17.2

### *Transferability of skills*

**Problem solving** In the comments on Activity 8.2 we showed how two people had transferred the problem-solving approach developed in Block 5 to a new context. In one case, the formal procedure was applied, and in the other just a broad outline was used. It's hard to set out a general strategy that is applicable to solving *all* problems, but it usually helps to make sure you know what the starting point and end point are, and to be aware that there are often a variety of ways to solve a problem, so that if you get stuck you can try a different approach. Sometimes if you are stuck it's possible to begin at the end and work back from there. Problem solving is not necessarily a linear process — it can involve jumping forwards, backwards and even sideways.

It is important that you should develop your own strategy (or strategies) for solving problems that you encounter, because only you will be aware of what works for you. If you have the opportunity, it would be worth discussing problem solving with other students. You will find that skills you learn in physics, say, can be used in chemistry, Earth science and biology. Indeed, learning how to solve science problems can help you to solve problems in all kinds of other areas, such as with managing cash flow, or staff, or a household, or limited resources (like not enough time!). This is what we mean by 'transferability of skills'.

**Classifying** There are many places where a system of classification is used in this block. To take two examples from the last few sections, organic compounds have been classified by their functional groups as alkenes, carboxylic acids, alcohols, esters, amides, and so on. Reactions of organic compounds have been classified as addition, condensation, hydrolysis, oxidation and reduction. You will be able to recall many other



examples of the use of classification in this block and in previous blocks. Clearly, scientists often choose to classify things.

Classification requires us to pick out key similarities and differences between items, and it is useful when there is too much information to comprehend and remember readily. We can make more sense of the information when it is organized in some way. For example, if we remember the reactions of carboxylic acids, we do not have to remember separately how acetic acid, propanoic acid, stearic acid, and lots of other organic acids each react.

Classification schemes often make it easier to make sense of new information about the items in the scheme. For example, you already knew about the highly reactive alkali metals and their positions in the Periodic Table from Block 6, and so learning that they have one electron in their outer shell (electron configuration  $ns^1$ ) can easily be added to this classification. Indeed, this additional information can then be used to help you to understand and retrieve information on the way that many elements react.

Moreover, if you can identify an 'item' that you know very little about within a certain class and you know how that class of things behave, then you can predict the properties of the 'item'. For example, if you knew that decanoic acid was a carboxylic acid, you could predict what reactions it would undergo and what the products would be.

### *Transferability of techniques*

There are a variety of ways of keeping track of important techniques. Perhaps the simplest is a list of the techniques, divided up by block, with references to the places where you can find examples that illustrate the use of each technique. The references might be to your answers and notes for questions and activities, and for these references to be useful you need to have an effective way of filing your answers and notes so that you can easily find them. Alternatively, and rather more time-consuming to implement, you could keep a separate file of 'useful techniques', with each technique illustrated with a specific example and by a summary of the general procedure for using it.

You will need to decide which techniques to keep a record of. From this block, you have developed strategies for:

- working out the effects of change in temperature, pressure and other constraints on rates of reaction and equilibrium yield;
- analysing the structure of organic compounds;
- drawing structural formulae;
- predicting the products of an organic reaction.

You may have included other examples. Also, while studying other blocks you will have developed techniques and strategies covering numerous areas, ranging from plotting graphs to manipulating algebraic expressions, and from planning a piece of writing to reaching an understanding of a difficult concept. Since you have already worked out all these strategies, all you need to do is to make sure they are accessible and in a form that is useful to you. It is a good idea to have both a generalized description of the steps you take and also a specific example to illustrate them.

### *Transferability of information*

The best place to start to track down information on specific topics will often be the Course Glossary; this will tell you which block to refer to for more detailed information, and you can then use the index in the book or the contents list to find what you need. Of course, sometimes you will not have access to all of your course materials, and you will then need to keep a list of 'things to look up / find out'.

It's worth making a note of the information you locate and where you found it, or you may find yourself going through the process of searching it out all over again! The extent of your notes will depend on the situation; it may be sufficient to make a note of the block and page number, plus a few words that indicate the relevant information that you found there. However, you may wish to make more detailed notes of a section if you are about to produce an answer to a TMA question.

Synthesis then involves doing something with the relevant material you have retrieved from all over the place. For example, you may have to write an account for a TMA question, and your tutor will want to read an account that has a good structure and a logical flow. Getting your hodge-podge of relevant information and arguments into order is essential, and we recommend that you do most of the thinking, planning and re-ordering before you start writing. During the planning process you will often realize that there are 'gaps' in the information you have gathered, and this will prompt you to search for the information required to fill the gaps. You will also find that some of the information gathered is not relevant to the account you are writing, and need not be included.

## Objectives for Block 8

The objectives state what you should understand and what you should be able to do after studying the block.

The numbers of the questions and activities that test each objective are given in italics. In the margin next to some objectives are references to *The Sciences Good Study Guide* (SGSG), giving the chapter: section number or Maths Help (MH) number, or to CD-ROM material, where you can find additional support.

### Science content

- 1 Explain the meaning of and use correctly, all the terms printed in **bold** in the text.
- 2 Identify the sub-shells in the shells with principal quantum numbers 1–4, and the maximum number of electrons that each sub-shell can hold. (*Questions 3.2 and 3.3*)
- 3 Given the atomic number of an element, and the appropriate sequence of s, p, d and f sub-shells in order of increasing energy, write down the electron configuration and the shell structure of the atom of an element. (*Questions 3.1, 3.4, 3.5 and 5.1; Activities 3.1–3.3*)
- 4 Relate the group and period numbers of a typical element in the Periodic Table to the outer electron configuration of its atom. (*Questions 3.1, 3.4 and 3.5; Activities 3.2 and 3.3*)
- 5 Distinguish ionic compounds and molecular substances, given their appropriate structural and physical properties. (*Questions 4.2, 4.3 and 5.6; Activity 4.1*)
- 6 State whether a binary compound formed from two typical elements is likely to be ionic or molecular, and relate this to the position of its elements in the Periodic Table and the concept of electronegativity. (*Questions 5.5 and 5.6*)
- 7 Draw structural formulae or abbreviated structural formulae for simple molecular compounds, given the valencies of the constituent elements, and write down the molecular formula that corresponds to a given structural formula. (*Questions 4.1, 4.4, 12.1–12.3, 12.6 and 12.7; Activities 12.1, 12.2 and 14.3*)
- 8 Write down the charge of an ion of a typical element in which the element attains the electron configuration of the atom of the nearest noble gas in the Periodic Table. (*Questions 5.1, 5.2, 5.5 and 5.6*)
- 9 Write down Lewis structures for simple molecular substances. (*Questions 5.3–5.6, 12.1 and 14.3*)
- 10 Relate the absorption or release of heat during a chemical reaction at constant temperature to the value of the enthalpy change, and to whether the reaction is exothermic or endothermic. (*Questions 6.1, 6.2 and 6.4*)
- 11 Calculate the enthalpy change per mole for a chemical reaction, given the enthalpy change (or the heat absorbed or released) when a given mass of substance reacts (and vice versa). (*Questions 6.3 and 6.5*)
- 12 Calculate the enthalpy change in a reaction in the gas phase, given appropriate information about bond enthalpies. (*Question 6.6*)
- 13 Explain the dynamic nature of chemical reactions at equilibrium. (*Question 7.1*)
- 14 Calculate the concentration of a solution, or of the ions in a solution, in mol litre<sup>-1</sup>, given the mass of solute in a given volume of solution, appropriate relative atomic masses, and the dissolution reaction of the solute. (*Question 7.2*)
- 15 Explain trends in boiling and melting temperatures in terms of intermolecular interactions, in particular, hydrogen bonds and London interactions. (*Questions 7.3–7.7*)
- 16 Recall the definitions of an acid and a base, and classify given substances accordingly. (*Questions 7.8, 9.1 and 9.2; Activity 7.1*)

- 17 Use Le Chatelier's principle to predict qualitatively how changes in the temperature, pressure, or concentration of a constituent, of a chemical reaction affect the equilibrium yield. (*Questions 8.1, 8.2, 8.5, 10.3–10.5 and 11.2; Activities 8.1 and 10.1*)
- 18 Calculate the value of the equilibrium constant for a reaction from values of concentrations of reactants and products present at equilibrium, and use the expression for the equilibrium constant to calculate unknown concentrations at equilibrium. (*Questions 8.3–8.5; Activity 8.2*)
- 19 Calculate the pH of a solution from either its hydrogen ion concentration or its hydroxide ion concentration, or vice versa, and state whether solutions are acidic or basic when values of these quantities are specified. (*Question 9.3; Activity 7.1*)
- 20 Predict and explain, in general terms, the effects of changes in concentration, in pressure, in temperature, or the effect of a catalyst, on the rate of a reaction. (*Questions 10.1, 10.3–10.5 and 11.2; Activity 10.1*)
- 21 Sketch (or recognize a correct sketch of) diagrams representing the energy barrier, and the internal energy of reactants and products, of a simple reaction. (*Questions 10.2 and 10.4*)
- 22 Explain the choice of reaction conditions (for example, pressure, temperature, catalyst) for an industrial process, given the thermochemical equation for the process. (*Questions 10.3–10.5 and 11.2; Activity 10.1*)
- 23 Classify organic compounds into classes and sub-classes, given the structural or abbreviated structural formulae or the functional groups that they contain. (*Questions 12.4 and 12.5; Activity 12.2*)
- 24 Identify isomers and identical representations of a given structural formula. (*Question 12.8; Activity 12.2*)
- 25 Describe the processes by which crude oil is converted into other compounds. (*Question 12.8; Activity 13.1*)
- 26 Identify functional groups in a molecule from its structural or abbreviated structural formula, and predict some of the reactions that the compound undergoes. (*Questions 14.1, 14.2, 14.4–14.6, 15.1, 16.1–16.3; Activities 14.1, 14.2 and 14.5*)
- 27 Explain the relationship between the structure of a polymer and the monomer(s) from which it is produced, and explain how physical properties of a polymer are related to its structure. (*Questions 15.2–15.5; Activity 15.1*)
- 28 Outline the reactions involved in condensation polymerization and in addition polymerization, and state whether specified molecules can undergo these reactions. (*Question 15.4; Activity 15.2*)
- 29 Outline the relationship between a drug and the enzyme or receptor on which it works. (*Questions 16.3–16.5*)

### Science skills

- |                |   |
|----------------|---|
| SGSG 8 2–4     | 30 Design an experiment, make observations, and record and interpret experimental results. ( <i>Activities 6.1, 7.1, 8.1 and 15.3</i> )   |
| SGSG 3:3 2–5.5 | 31 Identify trends and patterns in data presented in graphs and tables, and make predictions on the basis of these trends. ( <i>Questions 7.3 and 7.6; Activity 12.1</i> )  |
|                | 32 Use classification schemes to group items with similar properties together (e.g. ionic compounds/molecular substances, endothermic/exothermic reactions, compounds in crude oil, organic molecules with different functional groups). ( <i>Questions 12.4 and 12.5; Activities 4.1, 8.1 and 14.1</i> ) |

### Communicating science skills

- |             |   |
|-------------|---|
| SGSG 5: 2.5 | 33 Represent chemical substances and chemical reactions using the correct symbols, notation and formulae, and interpret chemical formulae and equations. ( <i>Numerous questions and activities</i> ) |
|-------------|---|



- |    |   |           |
|----|---|-----------|
| 34 | Present written answers to numerical questions in an appropriate way. ( <i>Most questions and activities involving calculations</i> )                                 | SGSG 14.5 |
| 35 | Construct a scientific argument by linking a set of facts in an appropriate way, and identify flaws in scientific arguments. ( <i>Activities 11.1 and 17.1</i> )      |           |
| 36 | Write a summary highlighting the similarities and differences between a group of processes. ( <i>Activity 13.1</i> )  | SGSG 9.3  |
| 37 | Locate information on a specified topic from various parts of the course material, and synthesize it to produce a written account. ( <i>Activities 6.2 and 17.1</i> ) | SGSG 9.5  |
| 38 | Read a scientific article in order to extract information on specified topics. ( <i>Activities 6.2 and 17.1</i> )   | SGSG 2    |

### **Mathematical skills**

- |    |  |                |
|----|--|----------------|
| 39 | Use ratios, percentages, proportions, decimals and powers of ten to solve chemical problems. ( <i>Most questions and activities involving calculations</i> ) | SGSG MH 1-5, 8 |
|----|--|----------------|

### **Effective learning skills**

- |    |  |  |
|----|--|--|
| 40 | Develop general strategies for tackling particular types of problem. ( <i>Activities 8.2, 10.1 and 14.2-14.5</i> )   |  |
| 41 | Transfer skills developed in a particular context to a different context, and adapt them appropriately for the new context. ( <i>Activities 8.2 and 17.2</i> ) |  |

## Who produced Block 8?

S103 *Discovering Science* was produced for the Science Faculty by a team drawn from many areas of the Open University. The full list of contributors to the course is printed in the S103 *Course Guide: Part II*.

Block 8 was produced for the S103 Course Team by the team of people listed below.

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## Appendix 1 Functional groups and their reactions

Functional group	Molecular structure	Alternative forms of molecular structure
alcohol	$R-OH$	$HO-R$
alkene	$\begin{array}{c} R^1 \quad R^2 \\ \diagdown \quad \diagup \\ C=C \\ \diagup \quad \diagdown \\ R^3 \quad R^4 \end{array}$	$R^1-CH=CH-R^2$
amide	$\begin{array}{c} O \\ \parallel \\ R-C \\   \\ NH_2 \end{array}$	$\begin{array}{c} O \\ \parallel \\ H_2N-C-R \end{array}$ $\begin{array}{c} O \\ \parallel \\ R^1-C \\   \\ NH \\   \\ R^2 \end{array}$ $\begin{array}{c} O \\ \parallel \\ R^1-C \\   \\ N-R^3 \\   \\ R^2 \end{array}$
amine	$R-NH_2$	$H_2N-R$ $\begin{array}{c} R^2 \\   \\ R^1-N \\   \\ H \end{array}$ $\begin{array}{c} R^2 \\   \\ R^1-N \\   \\ R^3 \end{array}$
carboxylic acid	$\begin{array}{c} O \\ \parallel \\ R-C \\   \\ OH \end{array}$	$\begin{array}{c} O \\ \parallel \\ HO-C-R \end{array}$
ester	$\begin{array}{c} O \\ \parallel \\ R^1-C \\   \\ O-R^2 \end{array}$	$\begin{array}{c} O \\ \parallel \\ R^2-O-C-R^1 \end{array}$

### Addition



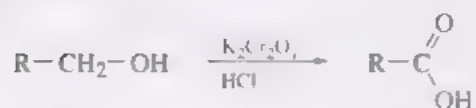
### Condensation



### Hydrolysis



### Oxidation



### Reduction



## Appendix 2 What to do if you are short of time

This brief guide to the activities in Block 8 should help you to decide for yourself whether you need to do a particular activity. Remember, though, that if you have the time you should aim to do *all* the activities in order to obtain the full benefit from your study.

The five numbered columns offer advice about each activity as follows:

- 1 essential that you do this activity at the particular point in Book 8 where it appears;
- 2 important, but there is more flexibility about when you do this activity, although you should try to complete it before moving onto the next section of Book 8;
- 3 may not be essential if you have some background already in the topic or skill, or have found earlier, similar activities straightforward;
- 4 could be left until later on, or dropped altogether if you are really short of time;
- 5 forms a useful tool for revision before moving on to higher level Science courses, especially chemistry courses or S280. Part (b) of Activity 17.1 is useful preparation for the end-of-course assessment.

The last column on the right contains additional advice about some of the activities.

### Block 8 activities

Activity	Column 1					Comments
	1	2	3	4	5	
1	✓					
2		✓				
3		✓				
4	✓					Closely linked to book
6	✓					Closely linked to book
6.2			✓			
7.1		✓				
8	✓					Closely linked to book
8.2			✓			
9.1		✓				
11			✓			
11.1		✓				
12	✓					Closely linked to book
13.1			✓			
14.1	✓					Closely linked to book
14.2		✓				
14.3		✓				
14.4				✓		
14.5		✓				
15.1				✓		
15.2		✓				
15.3				✓		
17					✓	
17.2			✓			



## Appendix 2 Article for Activities 6.2 and 17.1

From *New Scientist* 15 January 1994. Reproduced with permission.

Will our love affair with the motor car ever end? Some day, it must—unless we can develop sustainable sources of energy to replace those we derive from fossil fuels. Will they be derived from renewable resources?

NewScientist  
**INSIDE SCIENCE**  
Number 68

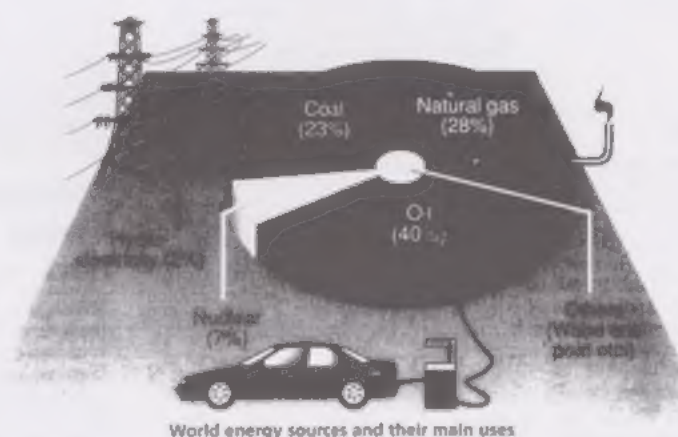
# ENERGY AND FUELS

John Emsley

EVERY day, the human race consumes a million billion kilojoules of energy by burning fuel. Every year, we burn up the same amount of energy as we would get from 8 billion tonnes of oil. In practice, though, we acquire only two-fifths of the energy from burning oil itself, the balance coming from other sources such as coal, gas and nuclear energy. Indeed, almost 90 per cent of our energy comes from fossil fuels which will one day run out. What will we do then? Are there alternative fuels to which we can turn?

We need energy for heating, generating electricity, and for transport which alone consumes about half of the 9 million tonnes of oil (8.5 billion litres) used every day. There are now almost 400 million passenger cars registered around the world; and this number has doubled in 20 years. In North America there are 50 cars for every 100 people, in Australia the figure is 45, in Britain and the rest of Europe it is around 40 and in Japan 30. The world average is 10, with countries like India and China still having fewer than 1. Cars especially need a liquid fuel that can power their engines. Most run on petrol but the number running on diesel is growing. Could they all be fuelled from renewable resources, perhaps ones that, unlike existing fuels, do not pollute the atmosphere?

So far, the discovery of fossil fuel reserves has more than kept pace with demand. Known resources now exceed a trillion ( $10^{12}$ ) tonnes in total compared with just over half this amount 20 years ago. Natural gas and oil consist mainly of hydrocarbons, which make excellent fuels. The main components of natural gas are methane ( $\text{CH}_4$ ), the simplest hydrocarbon, and small quantities of ethane ( $\text{C}_2\text{H}_6$ ), propane ( $\text{C}_3\text{H}_8$ ) and butane ( $\text{C}_4\text{H}_{10}$ ) gases, which can be produced from oil, are also



widely used, and are supplied in pressurised canisters, such as those used by campers. As the hydrocarbons get heavier, they become less volatile: petrol consists of so-called  $\text{C}_5$ s and  $\text{C}_{12}$ s, while diesel is  $\text{C}_{10-15}$ , and paraffin  $\text{C}_{12-20}$ . These heavier fractions make excellent liquid fuels for cars, lorries and aircraft respectively, and they release about 25 000 kilojoules per litre when they burn. Any replacements must burn with equal vigour. With this in mind, ethanol, methanol, esters and hydrogen are the principal renewable contenders.

## Renewable fuels Running on the grain

THE BRAZILIANS run their cars on ethanol made from sugar cane. The Americans make ethanol from surplus grain. In Europe, we convert rapeseed oil into esters and use the liquid as a substitute for diesel fuel in buses and boats.

"Biofuel" is the general term for sustainable fuels because the source is harvestable. Solid biofuels, such as firewood, are abundant. Fast-growing saplings and elephant grass could be harvested and burnt to generate heat and produce electricity. But liquid biofuels are trickier to extract, store, distribute and use. Some crops give particularly high yields of oils. For example, the gopher plant (*Euphorbia lathyris*)

oozes a milky-white latex sap that could be used as a raw material for the oil industry, while the Brazilian tree (*Copaifera langsdorffii*) yields sap which can be used to replace diesel directly in engines. Yet neither plant has been developed as a source of fuel and instead, people have focused on existing food crops.

Ferment sugar and you produce ethanol, better known as alcohol. Brazil, Zimbabwe and the US produce

this as a fuel. The Brazilians hoped that ethanol would ease their growing need to import oil. In the late 1970s oil doubled in price to \$40 a barrel (132 litres), or about \$65 at current prices. Weight-for-weight, ethanol does not release as much energy as petrol. But in terms of volume, the fuels almost match, ethanol releasing 23 000 kilojoules per litre against 25 000 for petrol. By 1990, the Brazilians were growing 25 million tonnes of sugar cane a year on 4 million hectares (8 per cent of their cultivated land), and turning three-quarters of it into 12 billion litres of ethanol.

Today, Brazil has four million cars running on ethanol, and another million which burn a mixture of 20 per cent ethanol and 80 per cent petrol by volume. One quarter of Brazil's transportation fuel is ethanol, down from a peak of 28 per cent in 1989. It once looked as though all Brazilian cars would eventually run on ethanol, but oil is now much cheaper at around \$15 per barrel and Brazil is exploiting its own plentiful reserves of this. Ironically, the Brazilians now add petrol to ethanol as a way round their "problem" of producing excess petrol domestically, whereas other countries are now adding alcohol to petrol to reduce pollution.

In terms of cost, ethanol can no longer compete with petrol. This is despite the Brazilian government buying the electricity generated by burning sugar cane residues,



farmers increasing sugar cane yields from 65 tonnes per hectare to 77 tonnes per hectare, and manufacturers boosting alcohol production by 15 per cent with better methods of fermentation and distillation. Ethanol is still used because, as a so-called oxygenated fuel, it produces less pollution when it burns. Ethanol enabled Brazil to be one of the first countries to phase out leaded petrol, to cut the level of poisonous carbon monoxide in the air of its cities, and to eliminate photochemical smog caused by unburnt hydrocarbons. Clean-burning ethanol means that São Paulo, which has 20 million inhabitants, still has relatively clean air.

The US, meanwhile, produces more than 3.5 billion litres of ethanol a year by fermenting the starch of surplus corn and grain. The plan is to double this by the year 2000, and much of it will end up in reformulated blends of gasoline to ease urban pollution problems.

## Turning yellow Essence of ester

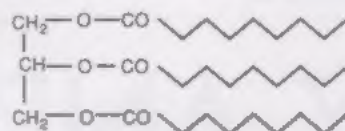
FARMERS in Britain grow more than a million tonnes of rapeseed per year, almost all of it for human consumption, although in the past rapeseed oil was turned into synthetic rubber, soap and lubricants. Rape's scientific name is *Brassica napus* but its common name comes from *rapum*, the Latin for turnip. It can be used as a heating oil, but rape methyl ester, or RME, is now a renewable replacement for diesel. RME offers environmental benefits; it emits fewer sooty particles than ordinary diesel and no sulphur dioxide (which can cause acid rain). A tonne of crushed rapeseed produces about 320 kilograms of oil.

Nowadays, most RME is made by the Italian firm Novamont, which supplies it for public transport in some Italian cities, for lorries in Austria, taxis in Berlin and Bologna, and for the Lake Como ferry in Northern Italy. Last year, two buses in Reading ran on it for a six-month trial, and two boats on the Norfolk Broads were fuelled with it. The problem is that while diesel oil costs about 10p per litre, RME imported from Italy costs 24p.

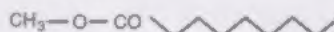
Nevertheless, the managing director of the Reading Bus Company, Rod Wilson, said he was highly pleased with it. He believes that local production would halve its price to match that of diesel. Factories to make RME are being built in several European countries and, says David Koch of Novamont, production could reach more than 500 000 tonnes a year by the end of the decade. The French aim to grow rapeseed for biodiesel

## 1. Fuels from natural fats: the sheep connection

ALL vegetable oils and animal fats are made up of molecules called **triacylglycerides**, so called because they consist of three long-chain fatty acids connected to the small molecule called glycerol:



Plants and animals make oils and fats because their long chains of  $\text{CH}_2$  units provide a way of storing energy efficiently. However, they clog up engines with glycerol residues after a few days. It is better to liberate the fatty acids from glycerol with alkali. The resulting acids are then treated with methanol ( $\text{CH}_3\text{OH}$ ) which converts them into methyl esters, for example:



These are more volatile and so are more suitable for use in diesel engines. In theory, animal fats could also be turned into biodiesel and a few years ago this was proposed as a way of using up unwanted tallow from sheep in New Zealand.

on 700 000 hectares of their land.

Algae can also make oil and, given the right conditions, these primitive plants can

double their numbers five times a day. Some algae convert half their mass into oil. They grow well in polluted water and even thrive in water that is saltier than the sea. In a sunny climate, a hectare-sized pool could produce 120 tonnes of algae a year, more than double the yield from the same area of rape or sugar cane. Paul Roessler of the Solar Energy Research Institute (SERI) in Golden, Colorado, claims that such a pond could yield up to 100 000 litres of fuel per year. The oils would be converted into their methyl esters. The institute is evaluating the primitive diatoms *Chaetoceros* and *Navicula* and also *Monoraphidium*, a green algae, as possible candidates for algal fuel.

Paul Jenkins of the University of the West of England, in Bristol, is now researching algal fuel. He is focusing on the common green algae of ponds, *Chlorella*. The algae would be filtered out of a special coil where they grow and burned in an engine to generate electricity. The carbon dioxide emissions from the engine would then be pumped back into the coil to encourage algal growth. The nutrients that algae need could come from sewage.

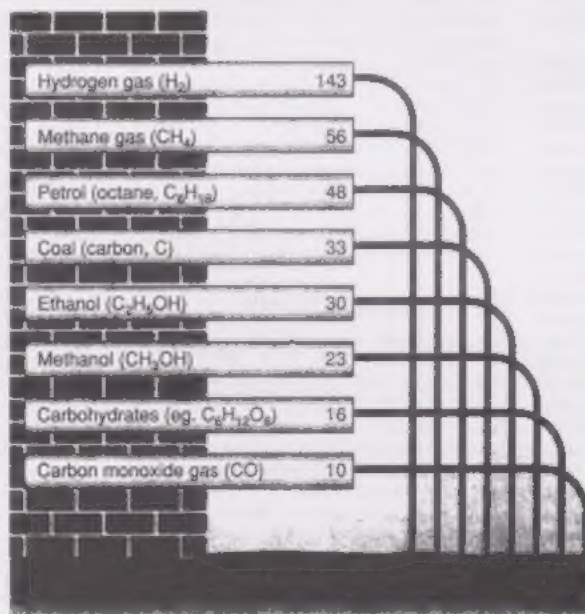
## Hydrogen hopes Rocket fuel for cars

BESIDES ethanol and esters, there are alternative fuels, currently produced from fossil fuels, which could be made from sustainable resources. These are hydrogen and methanol.

When hydrogen burns, 1 gram yields more energy than the same amount of conventional fuels. Some people talk of a "hydrogen economy" emerging in the future, but the problem is storing it—a tonne of hydrogen occupies 11 million litres, which is about the size of a village church. Moreover, hydrogen is less dense than the natural gas, methane, and it requires three times the volume of gas to produce the same amount of heat. A lorry stacked with pressurised cylinders of hydrogen demonstrates the economic difficulties: a 40-tonne truck transports less than half a tonne of hydrogen and a mere fraction of the energy of a loaded petrol tanker.

But condense hydrogen to a liquid at  $-253^\circ\text{C}$  and a tonne of the gas becomes a manageable 14 000 litres. This is how large quantities of hydrogen are transported and stored for powering rockets in the American space programme—the only vehicles which currently run on hydrogen. NASA is serviced by road and rail tankers carrying 75 000 litres (5 tonnes) at a time. One storage vessel at Cape Canaveral holds more than three million litres of liquid hydrogen.

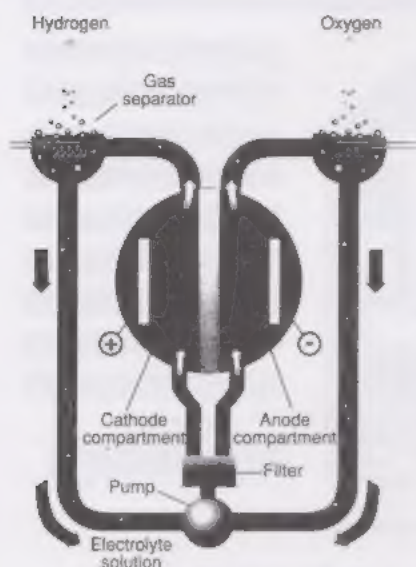
Hydrogen is already manufactured on a large scale for the



The energy waterfall: Each figure shows the kilojoules that are produced when a gram of fuel is burnt

15 January 1994





Splitting headache: Cells for making hydrogen are uneconomic

chemicals industry, and piped over hundreds of kilometres around Europe and the US. World production of hydrogen is around 350 billion cubic metres per year, about 30 million tonnes. There are two natural sources of hydrogen: water, and hydrocarbons such as methane.

When an electric current passes through water it releases hydrogen. Hydrogen generators work with 90-per-cent efficiency. The electrolysis of steam inside porous electrodes of zirconium oxide produces hydrogen even more efficiently. Even so, the process would not make a hydrogen economy viable. It is cheaper to produce electricity than to make hydrogen. But the surplus electricity produced by nuclear power stations at night could provide a cheap way of electrolysing water to make hydrogen.

Another way of generating hydrogen is to blow steam through white-hot coal to

produce a mixture of hydrogen and carbon monoxide gas, known as **synthesis gas**. Charcoal, a renewable fuel, could also be used:



At present, though, the best way of making hydrogen is from alkanes such as methane and propane by treating them with steam at about 1000 °C. This gives a mixture that is 75 per cent hydrogen by volume. Getting pure hydrogen gas from such a mixture is no problem, thanks to a curious property of the element palladium. A thin sheet of this metal allows hydrogen alone to filter through.

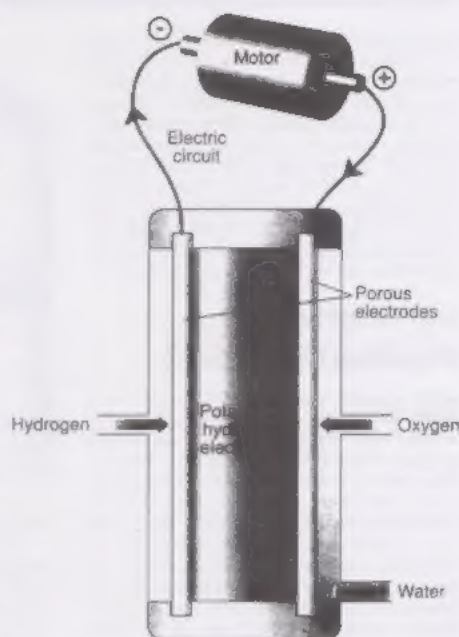
Although hydrogen is used as a fuel only in space rockets, there are plans to use it in vehicles. Shoichi Furuhashi and colleagues at the Musashi Institute of Technology in Tokyo have added a spark plug to a diesel engine so it will ignite hydrogen gas under a pressure of 10 megapascals (100 atmospheres). Their car will travel 300 kilometres on a 100-litre tank of liquid hydrogen. The hydrogen is carried in a stainless steel, vacuum-insulated, tank.

Hydrogen can also be absorbed and stored in certain metal alloys. Mazda has built a car which stores hydrogen in this way. Titanium, iron, magnesium and nickel alloys can absorb the equivalent of their own volume of liquid hydrogen and release it as it is needed. But they lose the capacity over time as the metal becomes brittle and powdery. The hydrogen need not be burnt as a gas in an engine, and could run an electric motor instead, which would draw its current from a fuel cell using hydrogen. In 1991, the European Community's Eureka research programme started a project, funded by the Swiss, British and German governments, to develop hydrogen-powered trucks and buses.

A third method for generating hydrogen

petrol containing 15 per cent of methyl tertiary butyl ether (MTBE). Almost two billion litres were produced in 1992.

Some critics, such as Larry Anderson of the University of Colorado, say that MTBE causes headaches, dizziness, sore eyes and nausea. But comparison between garage and forecourt workers in northern New Jersey, where MTBE is used, and those elsewhere in the state where MTBE is not needed, showed no differences in the types of symptoms or complaints. The unpleasant smell of MTBE may be the cause of the complaints. Extensive tests on rodents showed that it can be tolerated at high levels, and humans metabolise it rapidly to tertiary butyl alcohol. This is then discharged in the urine.

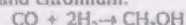


Fuel cells: Making electricity by making water. Methanol fuel cells are now also under development

is to split water into its component gases, oxygen and hydrogen, with sunlight. Powdered titanium dioxide doped with platinum metal was discovered to do this twenty years ago, but the amount of hydrogen given off is much too small to sustain a hydrogen economy.

## Methanol mania Brass from muck

METHANOL was once produced by heating wood chips, which is why it used to be called wood alcohol. Today it is made from synthesis gas, which can be converted into methanol by means of a catalyst of zinc oxide and chromium:



Methanol is a volatile liquid which boils at 65 °C and can fuel car engines. Racing car drivers who compete in the Indianapolis 500 race in the US choose it because it is clean-burning and, unlike petrol, it does not produce a fireball when a ruptured fuel tank catches fire in a crash. Most unleaded petrol contains 5 per cent methanol, or its derivative methyl tertiary butyl ether (MTBE). World demand for methanol now exceeds 20 million tonnes per year, compared with 14 million tonnes 10 years ago. Methanol can also be used in fuel cells to generate electricity. Instead of hydrogen gas releasing electrons at the anode of such a cell, methanol is used. Andrew Hamnett of the University of Newcastle upon Tyne is researching the method.

Methane, which accounts for

## 2. Fuel additives: clean-burn engines?

WHEN petrol burns in a car engine it does not all end up as carbon dioxide and water. Incomplete combustion produces pollutants such as unburnt fuel, oxides of nitrogen and carbon monoxide (CO). These can react together in air to form ground-level ozone, which harms plants and people even at quite low concentrations. Carbon monoxide is highly poisonous. To combat these hazards, the US government's 1990 Clean Air Act Amendment has decreed that oxygenated fuels must be used at certain times of year. Each winter, 39 American cities convert to



## INSIDE SCIENCE

between 85 and 99 per cent of natural gas by volume, is already used as a fuel for transport, and is supplied in cylinders. Around the world half a million vehicles run on so-called CNG—compressed natural gas—mainly in Italy, Canada and New Zealand. Converting a car to use CNG is easy because, like petrol, it burns well in spark-ignition engines. However, the fuel tank is heavy and bulky, and so reduces the luggage space limiting the distance that can be travelled on a full tank.

### Icy reserves Fluidised sand beds

VAST deposits of methane are locked away below the permafrost of Siberia and elsewhere and in many ocean sediments, trapped in ice crystals called gas hydrates. The crystals are 12 per cent methane and total gas reserves may be as much as 5 million trillion (10<sup>18</sup>) cubic metres. These may never be needed because methane is also a renewable resource and is a major by-product of sewage. It is generated in any organic matter that is decomposed in airless conditions by anaerobic bacteria. Methane can be extracted from decaying matter in rubbish tips. Both sources could be used to produce CNG after treatment to upgrade the quality of the gas recovered. It comes mixed with carbon dioxide and nitrogen which have no energy value. While the methane could be separated and sold as CNG, it is much easier just to burn effluent gas to produce heat, or to run turbines to generate electricity.

Other organic wastes, such as crop residues, could also be digested to yield

### 3. Petrol from fields: cars running on crops

COULD a country like Britain ever produce enough petrol from biological sources to support the present number of cars on our road? The answer is "yes".

The average family car travels about 13 kilometres per litre, consuming about 1250 litres of petrol each year. The country's 20 million cars would therefore need 25 billion litres. A hectare of fodder beet, one of Britain's most productive crops, will produce about 60 tonnes of carbohydrate, which would convert to about 28 tonnes of liquid fuel or roughly 40 000 litres. Britain would therefore need to grow about 600 000 hectares of this crop to meet its transport fuel needs. It could just about do it although it would mean planting an area eight times the size of London, or a third the size of Wales.

Would it ever happen? It seems unlikely since Britain is sitting on huge reserves of fossil fuels and it would always be cheaper to use these.



- a. Heating (gas) 45%
- b. Hot water (gas) 16%
- c. Lighting (elec) 1%
- d. TV etc (elec) 0.5%
- e. Cooking (elec) 3%
- f. Dishwasher (elec) 2%
- g. Fridge-freezer (elec) 2%
- h. Washer drier (elec) 0.5%
- i. Car (petrol) 30%

Energy used by a typical household. But who is wasting what and where?

methane, or they could be converted to liquid fuels. A lot of energy can be reclaimed by burning municipal waste as fuel in incinerators. In November 1992 a new £48-million power station was opened at Wolverhampton which burns 10 million old tyres a year. There are also schemes to convert waste into oil. Mehdi Taghiei of the University of Kentucky estimates that the US could generate 80 million barrels of oil from its plastic waste each year, which is 1 per cent of the annual consumption in the US. He has shown that mixing the waste with the hydrocarbon solvent tetralin and heating under a pressure of hydrogen gas at 450 °C for an hour will convert 90 per cent of the plastic into a light oil. Unlike ordinary crude oil, it is free of sulphur and is therefore easier to refine. BP Chemicals has found that a better way is to use a special reactor called a fluidised sand bed, which can turn almost all types of plastic into useful hydrocarbons. The plastics are heated at 400 to 600 °C and decompose to give off a mixture of petrol, diesel and paraffin.

Other wastes that can yield fuel are sawdust, newspapers and sewage. Heat and pressure will convert the cellulose from sawdust and newspapers into oil, mimicking the process that first produced fossil fuels—such as coal and gas—from ancient vegetation deep within the Earth's crust. When bacteria digest sewage in the absence of air, they generate methane gas. This is used in Europe as a fuel to generate electricity, although the process is only commercially viable if it is supported by subsidies from the European Community.

Sewage can also be turned directly into oil, a process that was shown to be feasible in 1987 by the Battelle Pacific Northwest Laboratories in the US. In this process, sewage sludge is made alkaline and then heated under pressure. This converts the organic material to crude oil, water and carbon dioxide.

### Liquid safety first Potential dangers

PETROL is a convenient fuel for cars because it is easy to handle and the fuel tank takes up little room in the vehicle. Yet it is highly combustible and therefore potentially very dangerous, especially so if the tank is ruptured in an accident. However, alternative fuels are not without their drawbacks. Hydrogen and CNG, being gases, pose safety hazards during frequent refuelling operations.

Of the alternatives, methanol is toxic and so poses a health hazard; and while it may be safer in a crash, it corrodes engines. Ethanol would seem to offer the best combination of convenience and safety of any liquid fuel, although a car needs a slightly larger fuel tank to give the same range between fillings. It does not present any difficulties with existing car engines, and when it burns it provides very little in the way of pollution.

### FURTHER READING

*The Essential Chemical Industry*, 2nd edition (Chemical Industry Education Centre, University of York, 1989). *BP Statistical Review of World Energy* (British Petroleum, 1993). *Biomass: Renewable Energy*, edited by D. O. Hall and R. P. Overend (John Wiley, 1987). *Motoring and the Environment* (Shell Briefing Service no. 2, 1992).

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